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United States Patent [19]

Bencheck et al.

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[45] Date of Patent: *Jun. 6, 2000

[54] **SYSTEM AND METHOD FOR UNREPORTED ROOT CAUSE ANALYSIS**

[75] Inventors: **Michael Bencheck**, Garland; **Robert Branton**, Farmers Branch; **Curtis Brownmiller**, Richardson; **Mark DeMoss**, The Colony; **Steve Landon**, Richardson; **Minh T. Tran**, Plano, all of Tex.

[73] Assignee: **MCI Communications Corporation**, Washington, D.C.

[*] Notice: This patent issued on a continued prosecution application filed under 37 CFR 1.53(d), and is subject to the twenty year patent term provisions of 35 U.S.C. 154(a)(2).
This patent is subject to a terminal disclaimer.

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[22] Filed: **Jun. 28, 1996**

[51] **Int. Cl.**[7] **H04L 12/26**; G05B 23/02

[52] **U.S. Cl.** **370/244**; 370/465; 340/825.06

[58] **Field of Search** ..... 370/241, 242, 370/246, 247, 248–250, 465, 466, 522; 340/521–523, 825.66, 825.01, 825.06; 364/514 B; 371/20.1, 20.2; 714/43, 47

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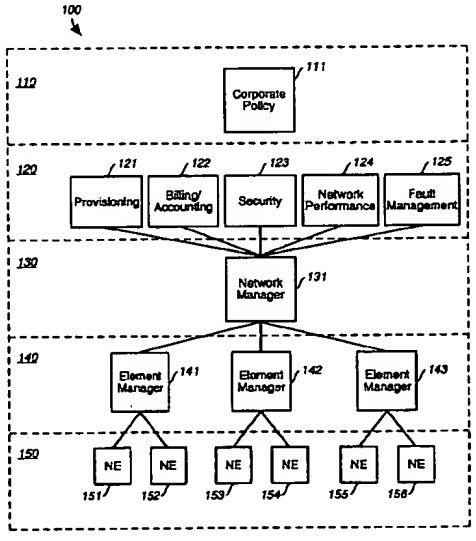
Primary Examiner—Chi H. Pham
Assistant Examiner—Steven Nguyen

[57] **ABSTRACT**

A system and method for determining a root cause of error activity in a network is described herein. Root cause analysis includes the correlation between reported error activity for path, line and section entities along a provisioned channel in the network. Root causes can also be identified based upon the correlation of simultaneous error activity on various signal transport levels. Finally, root cause analysis can correlate error activity along various path entities.

25 Claims, 17 Drawing Sheets



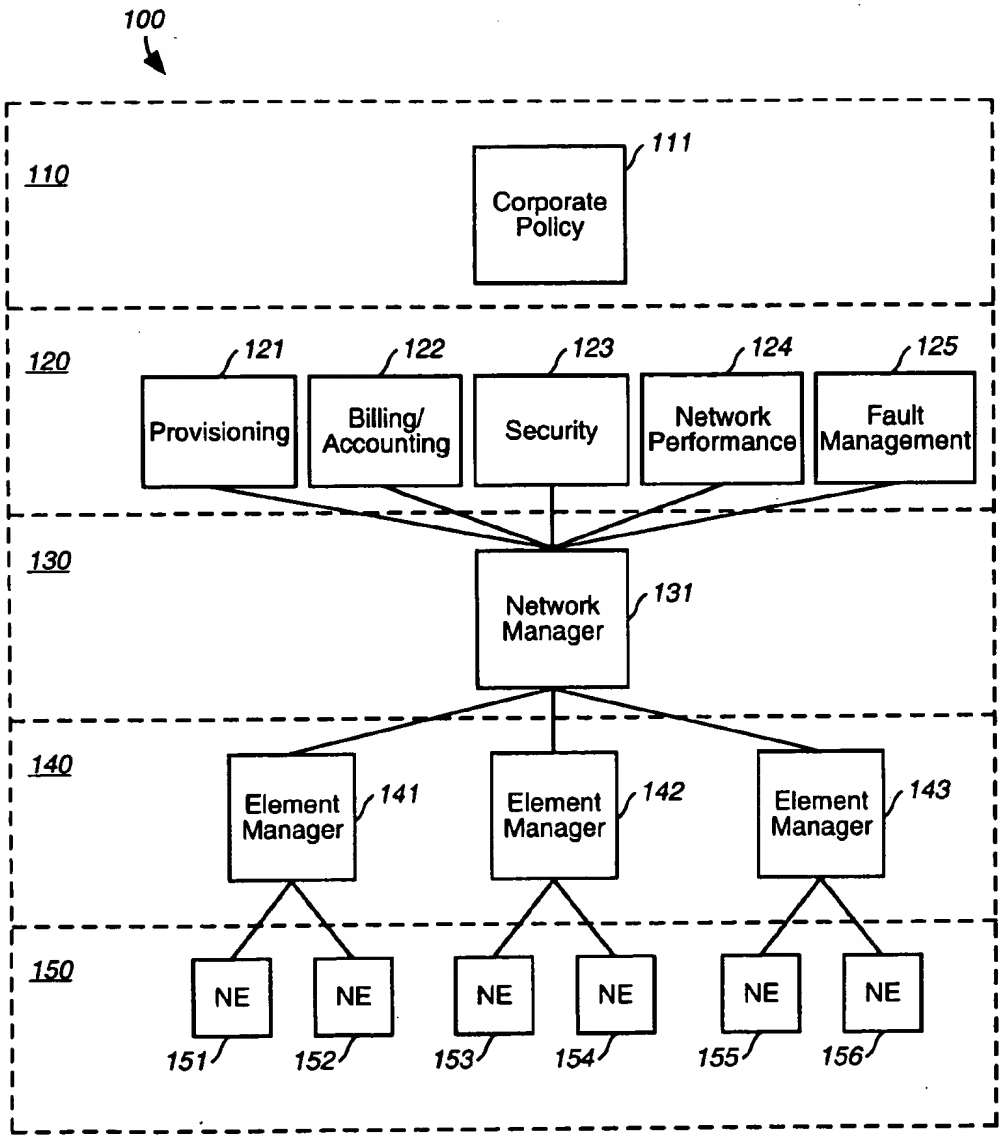

100
110
111
Corporate Policy
120
121
122
123
124
125
Provisioning
Billing/ Accounting
Security
Network Performance
Fault Management
130
Network Manager
131
140
Element Manager
141
Element Manager
142
Element Manager
143
150
NE
NE
NE
NE
NE
NE
151
152
153
154
155
156

FIG. 1

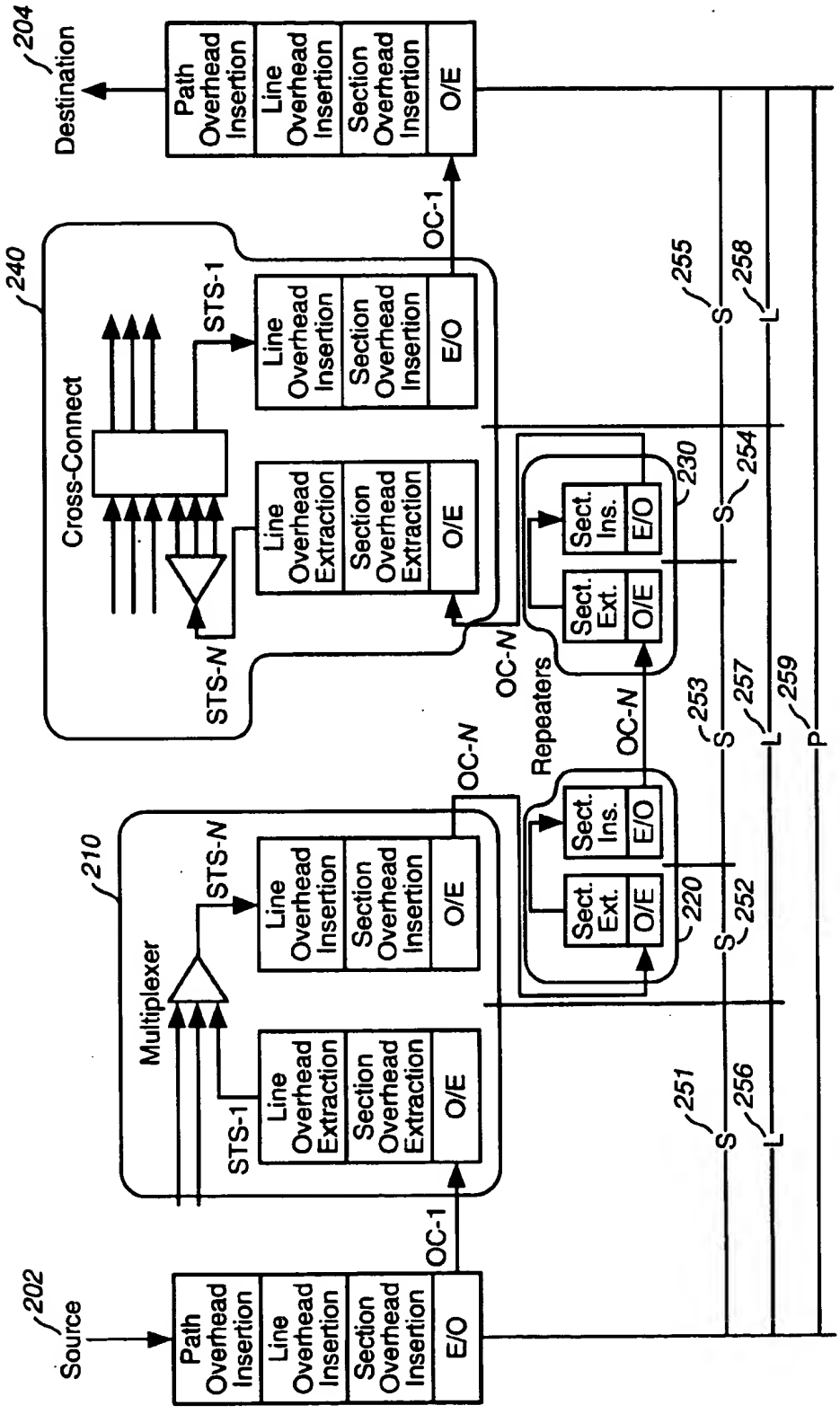

204
Destination
Path Overhead Insertion
Line Overhead Insertion
Section Overhead Insertion
O/E
OC-1
240
Cross-Connect
STS-1
Line Overhead Insertion
Section Overhead Insertion
E/O
Line Overhead Extraction
Section Overhead Extraction
O/E
STS-N
OC-N
Repeaters
Sect. Ins.
E/O
Sect. Ext.
O/E
230
220
210
Multiplexer
202
Source
255
258
254
253
257
259
252
251
256
S
L
P

FIG. 2

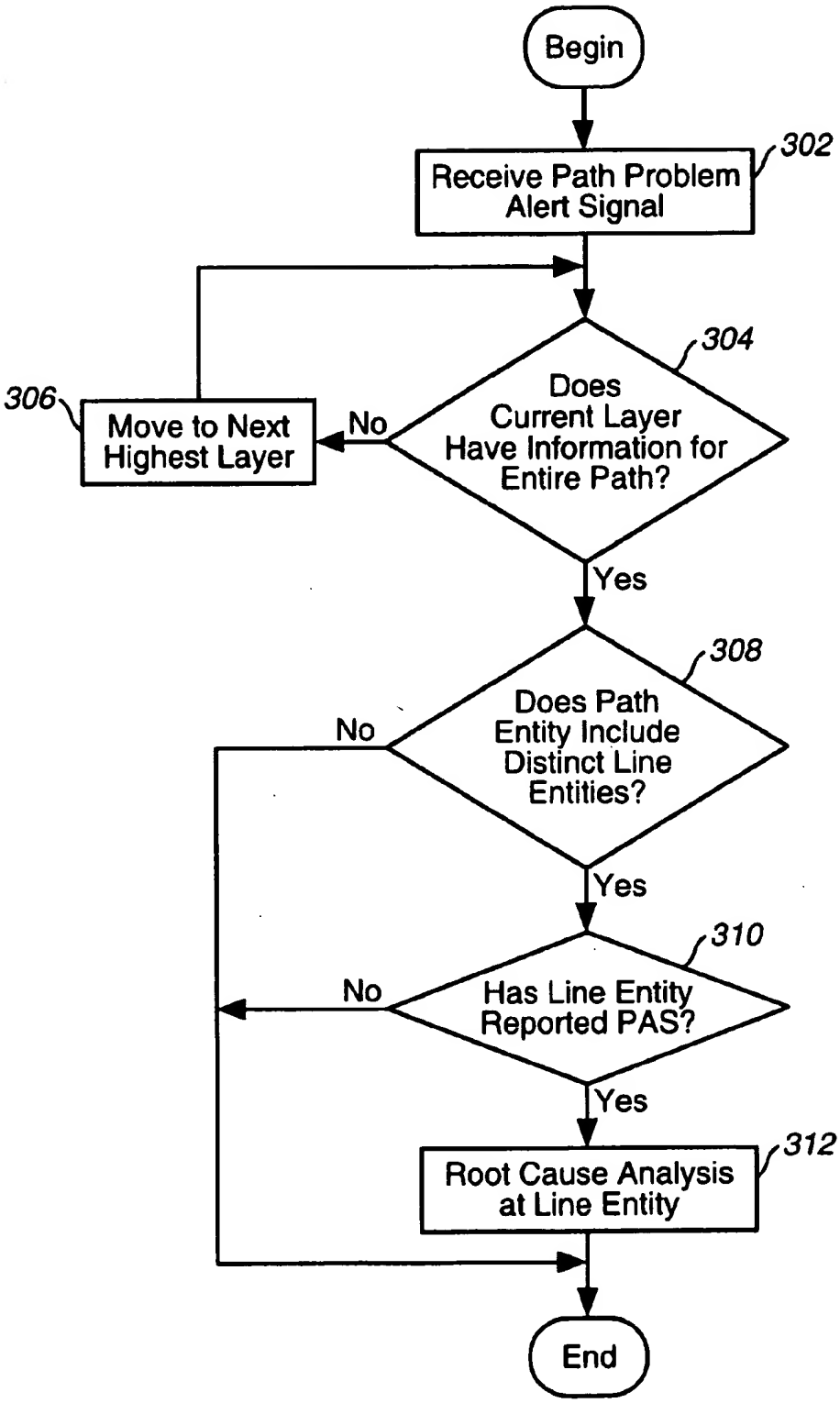

Begin
Receive Path Problem Alert Signal
302
Does Current Layer Have Information for Entire Path?
304
No
Move to Next Highest Layer
306
Yes
Does Path Entity Include Distinct Line Entities?
308
No
Yes
Has Line Entity Reported PAS?
310
No
Yes
Root Cause Analysis at Line Entity
312
End

FIG. 3

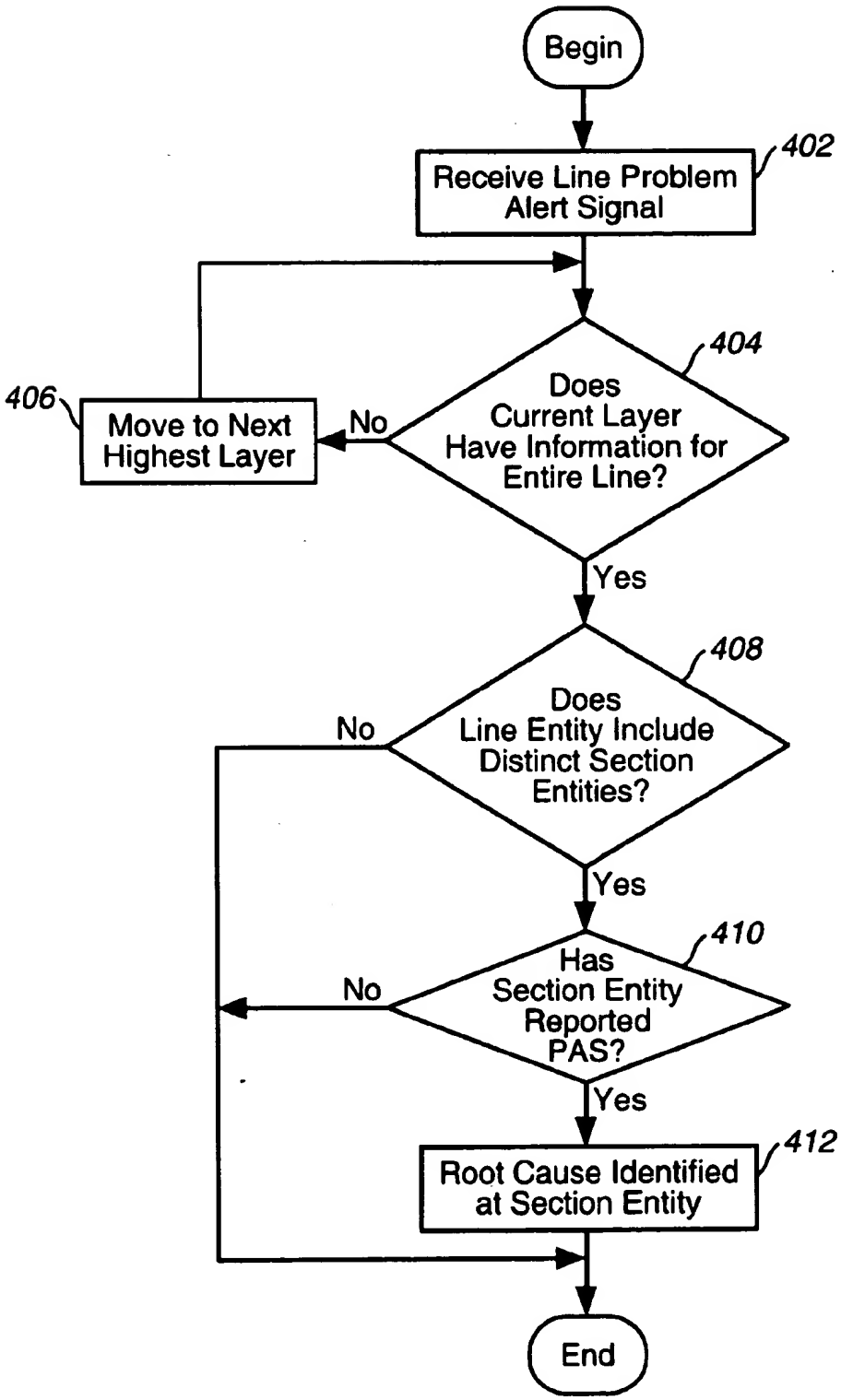

Begin
Receive Line Problem Alert Signal
402
Does Current Layer Have Information for Entire Line?
404
No
Move to Next Highest Layer
406
Yes
Does Line Entity Include Distinct Section Entities?
408
No
Yes
Has Section Entity Reported PAS?
410
No
Yes
Root Cause Identified at Section Entity
412
End

FIG. 4

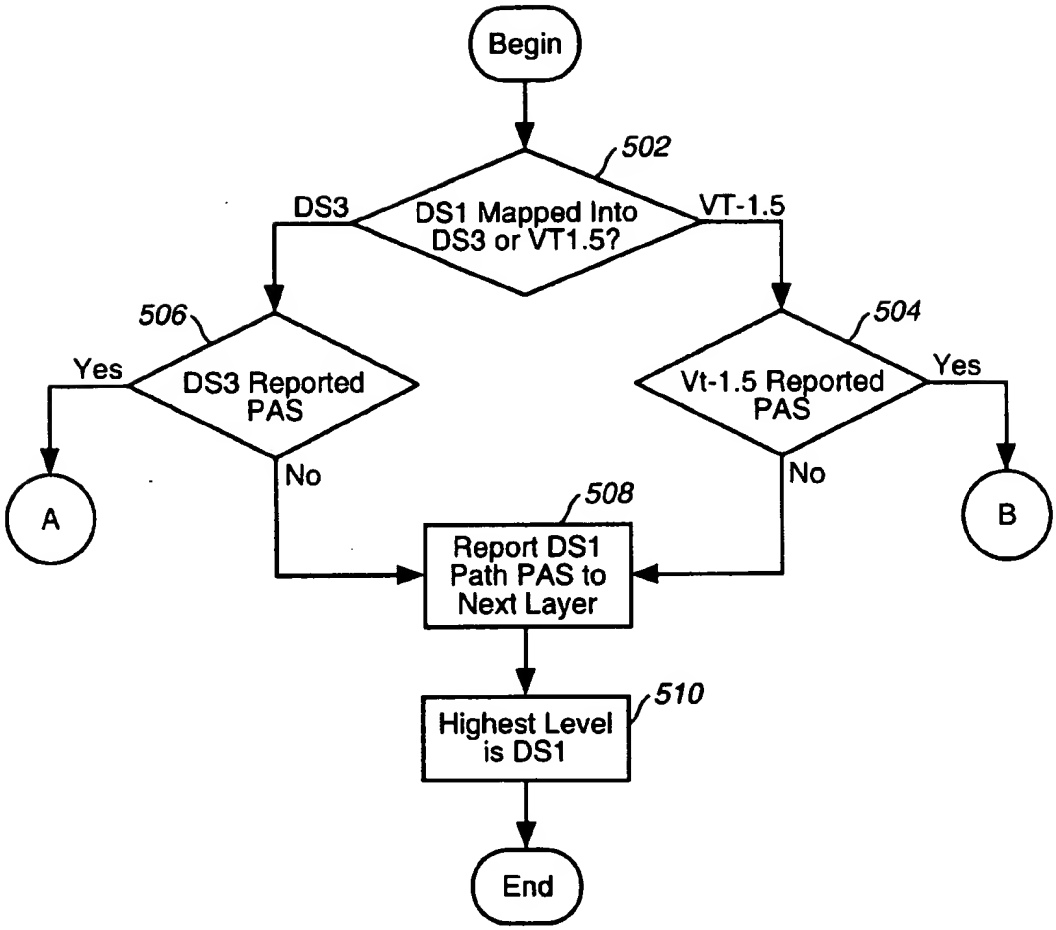

Begin
502
DS1 Mapped Into DS3 or VT1.5?
DS3
VT-1.5
506
DS3 Reported PAS
Yes
No
504
Vt-1.5 Reported PAS
Yes
No
A
B
508
Report DS1 Path PAS to Next Layer
510
Highest Level is DS1
End

FIG. 5A

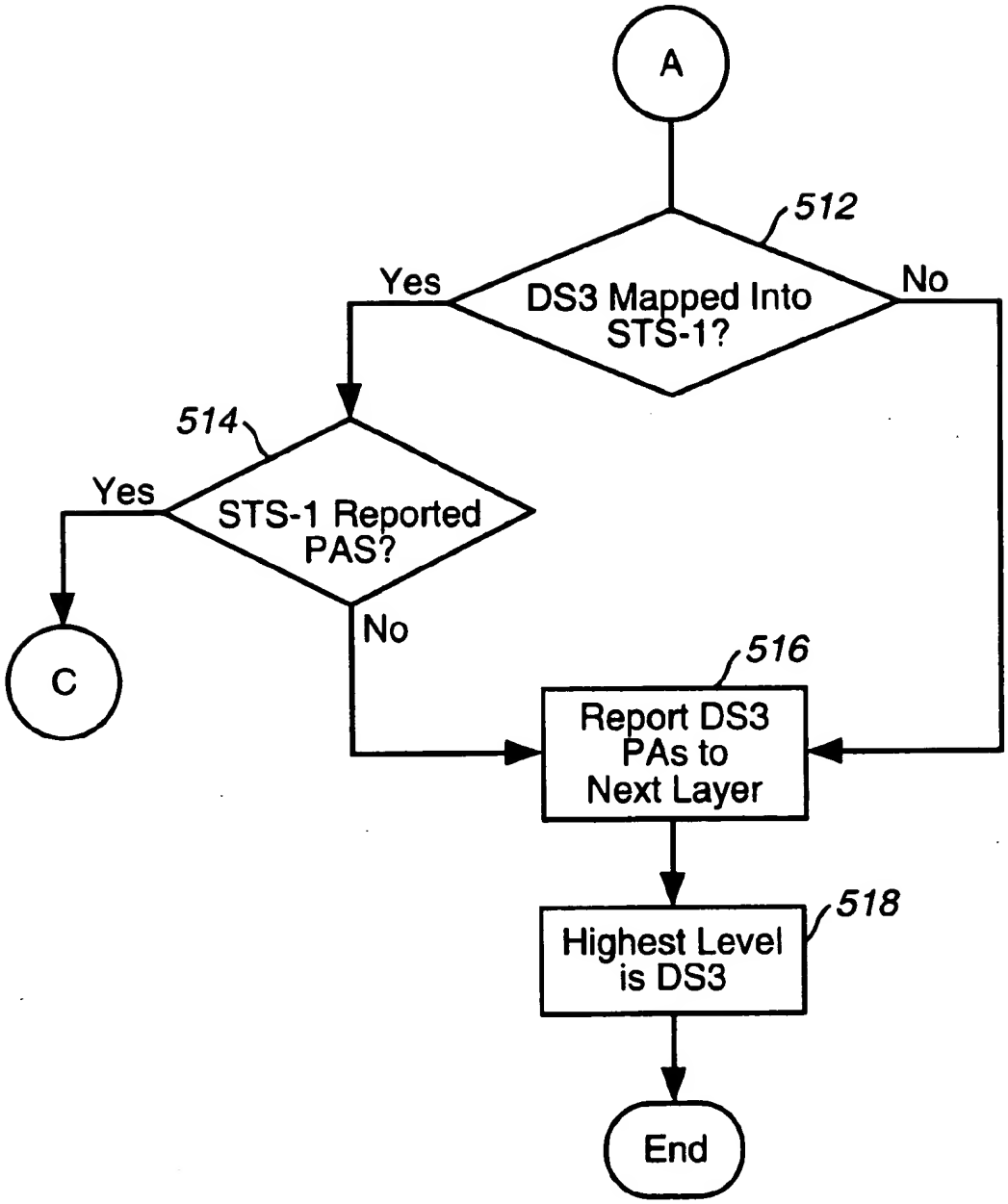

A
512
DS3 Mapped Into STS-1?
Yes
No
514
STS-1 Reported PAS?
Yes
No
C
516
Report DS3 PAs to Next Layer
518
Highest Level is DS3
End

FIG. 5B

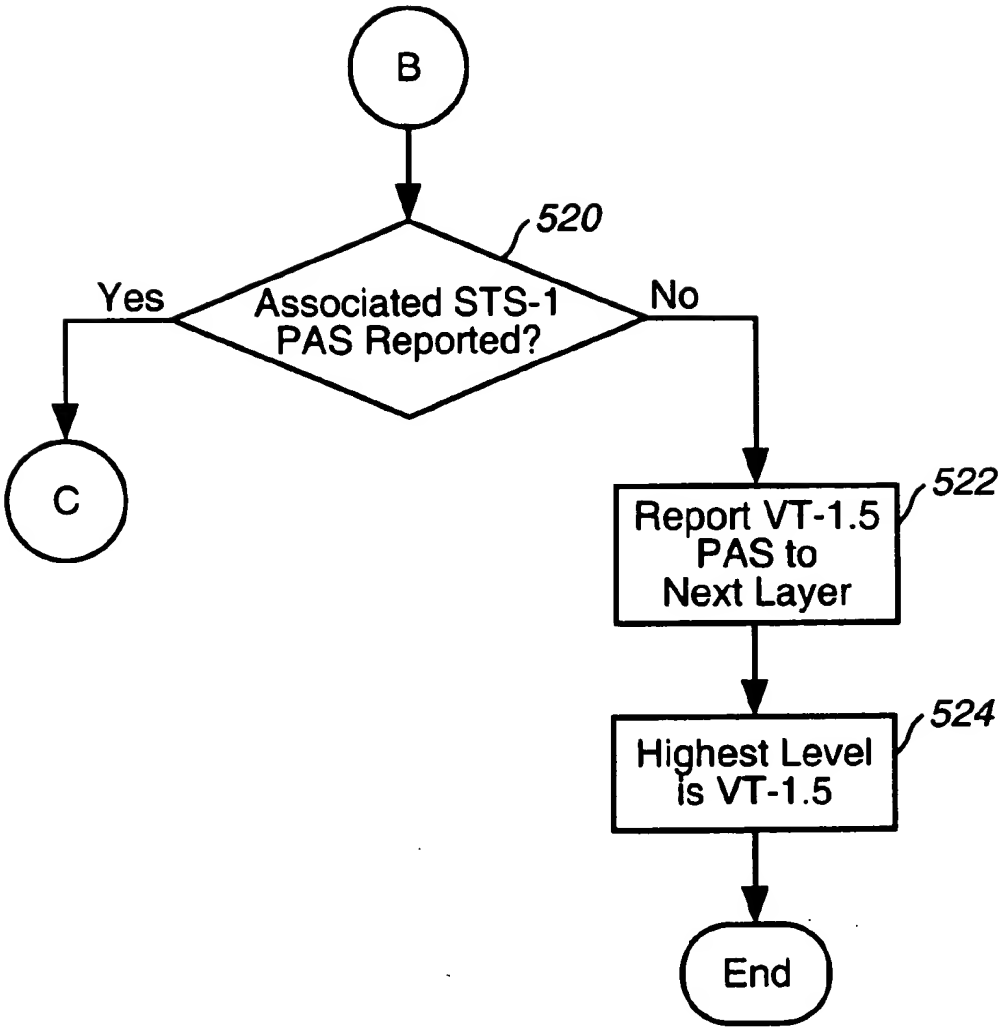

B
520
Yes
Associated STS-1 PAS Reported?
No
C
Report VT-1.5 PAS to Next Layer
522
Highest Level is VT-1.5
524
End

FIG. 5C

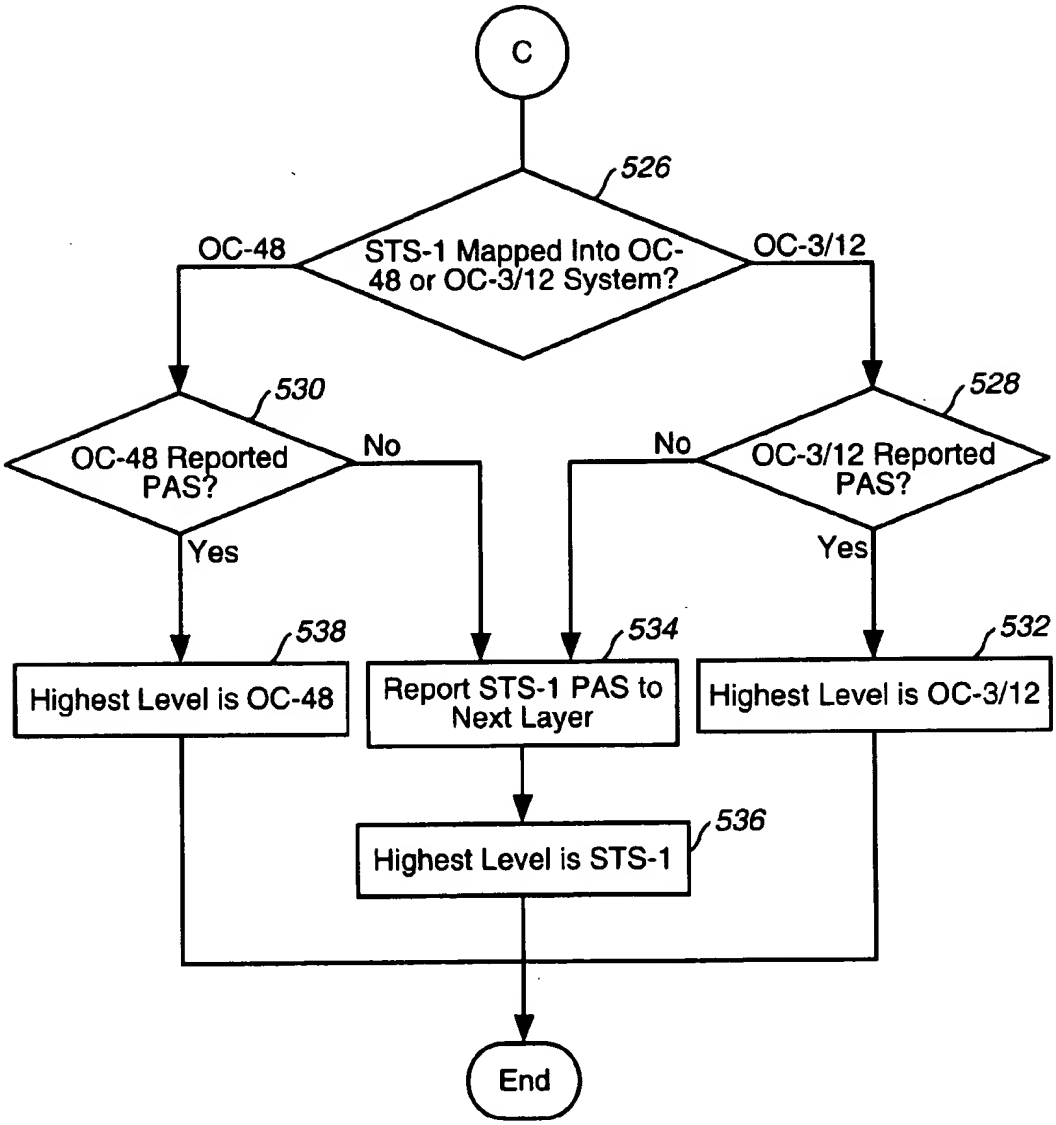

C
526
STS-1 Mapped Into OC-48 or OC-3/12 System?
OC-48
OC-3/12
530
OC-48 Reported PAS?
No
Yes
528
OC-3/12 Reported PAS?
No
Yes
538
Highest Level is OC-48
534
Report STS-1 PAS to Next Layer
532
Highest Level is OC-3/12
536
Highest Level is STS-1
End

FIG. 5D

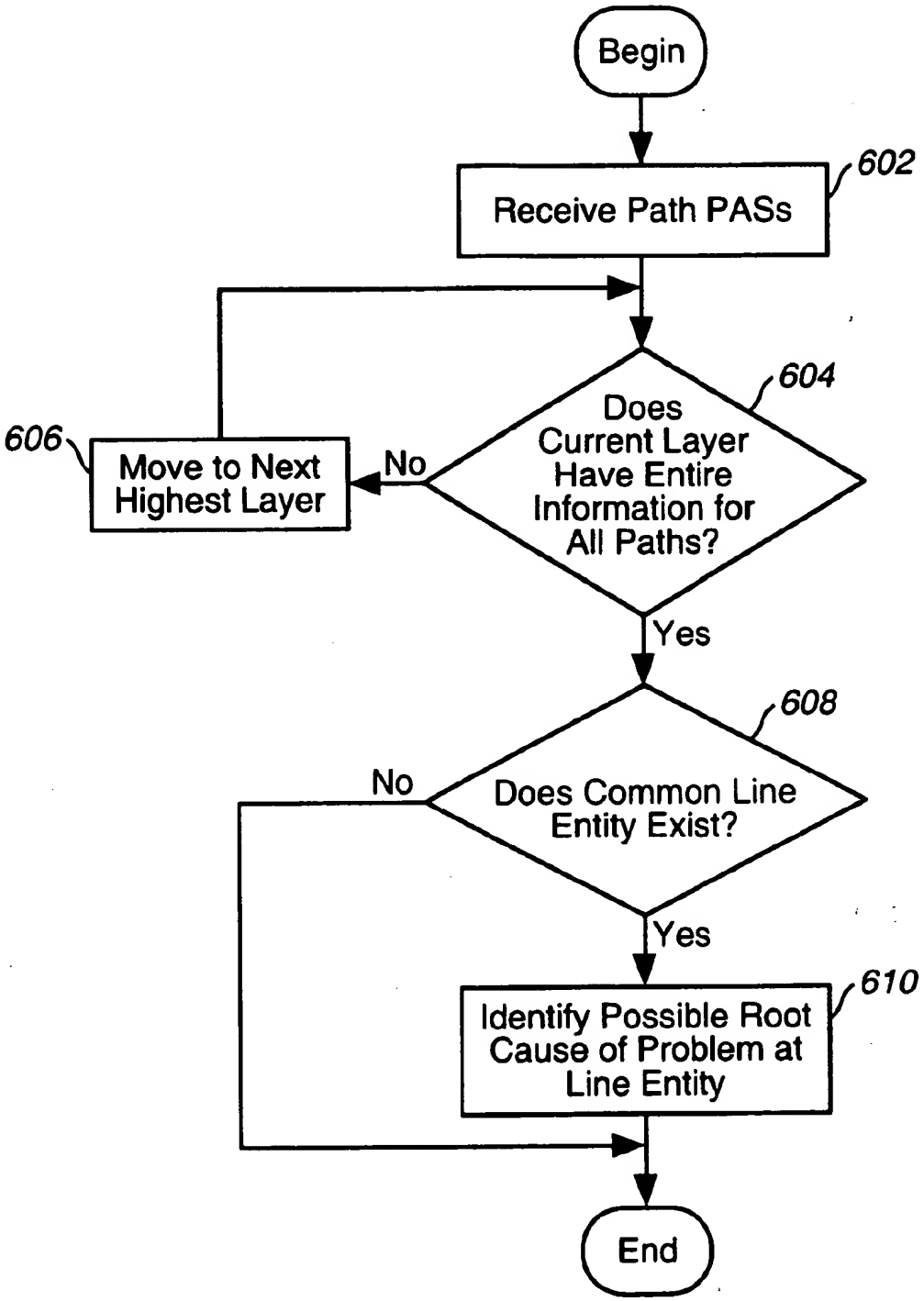

Begin
602
Receive Path PASs
604
Does Current Layer Have Entire Information for All Paths?
No
606
Move to Next Highest Layer
Yes
608
Does Common Line Entity Exist?
No
Yes
610
Identify Possible Root Cause of Problem at Line Entity
End

FIG. 6

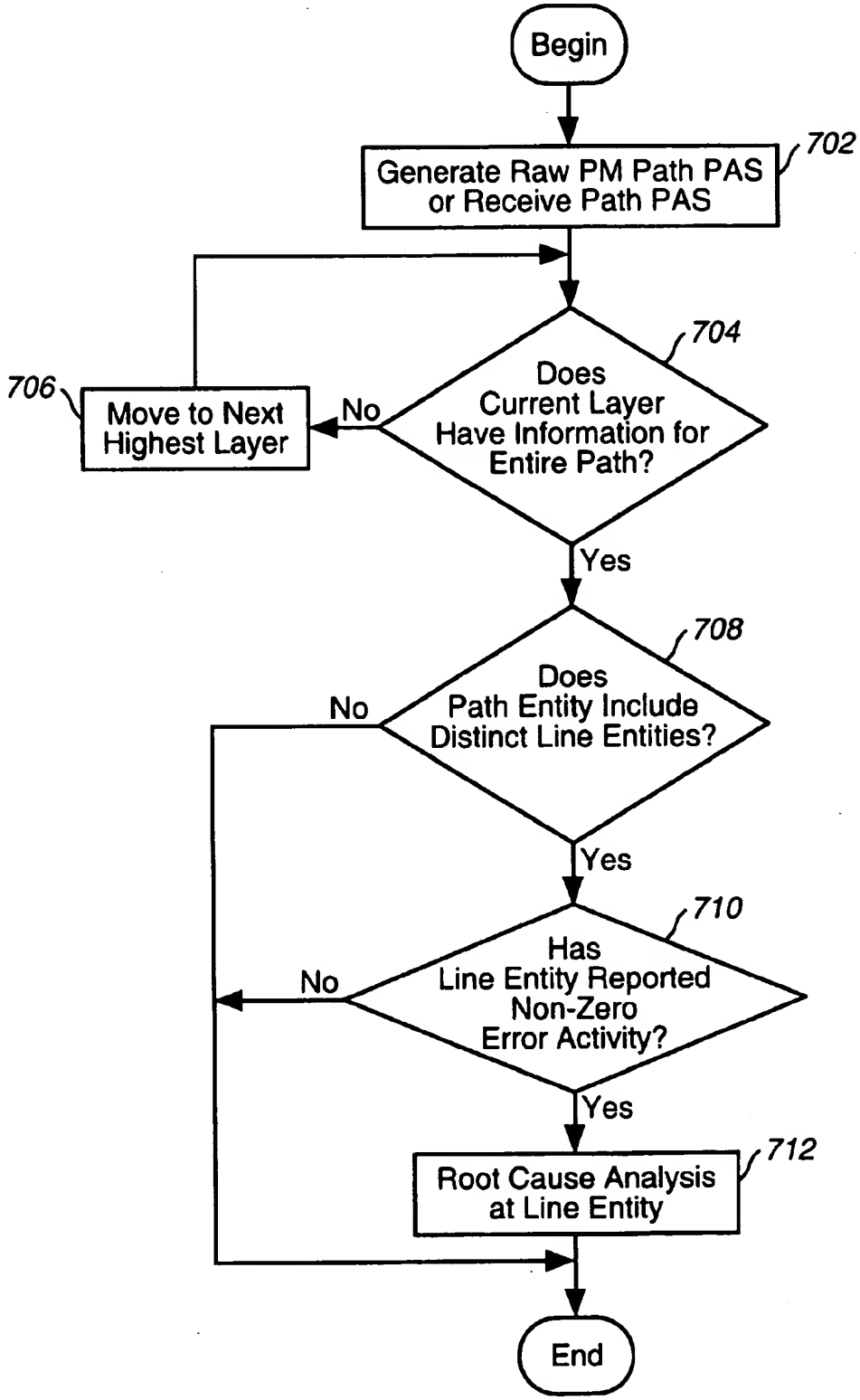

Begin
Generate Raw PM Path PAS or Receive Path PAS
702
Does Current Layer Have Information for Entire Path?
704
No
Move to Next Highest Layer
706
Yes
Does Path Entity Include Distinct Line Entities?
708
No
Yes
Has Line Entity Reported Non-Zero Error Activity?
710
No
Yes
Root Cause Analysis at Line Entity
712
End

FIG. 7

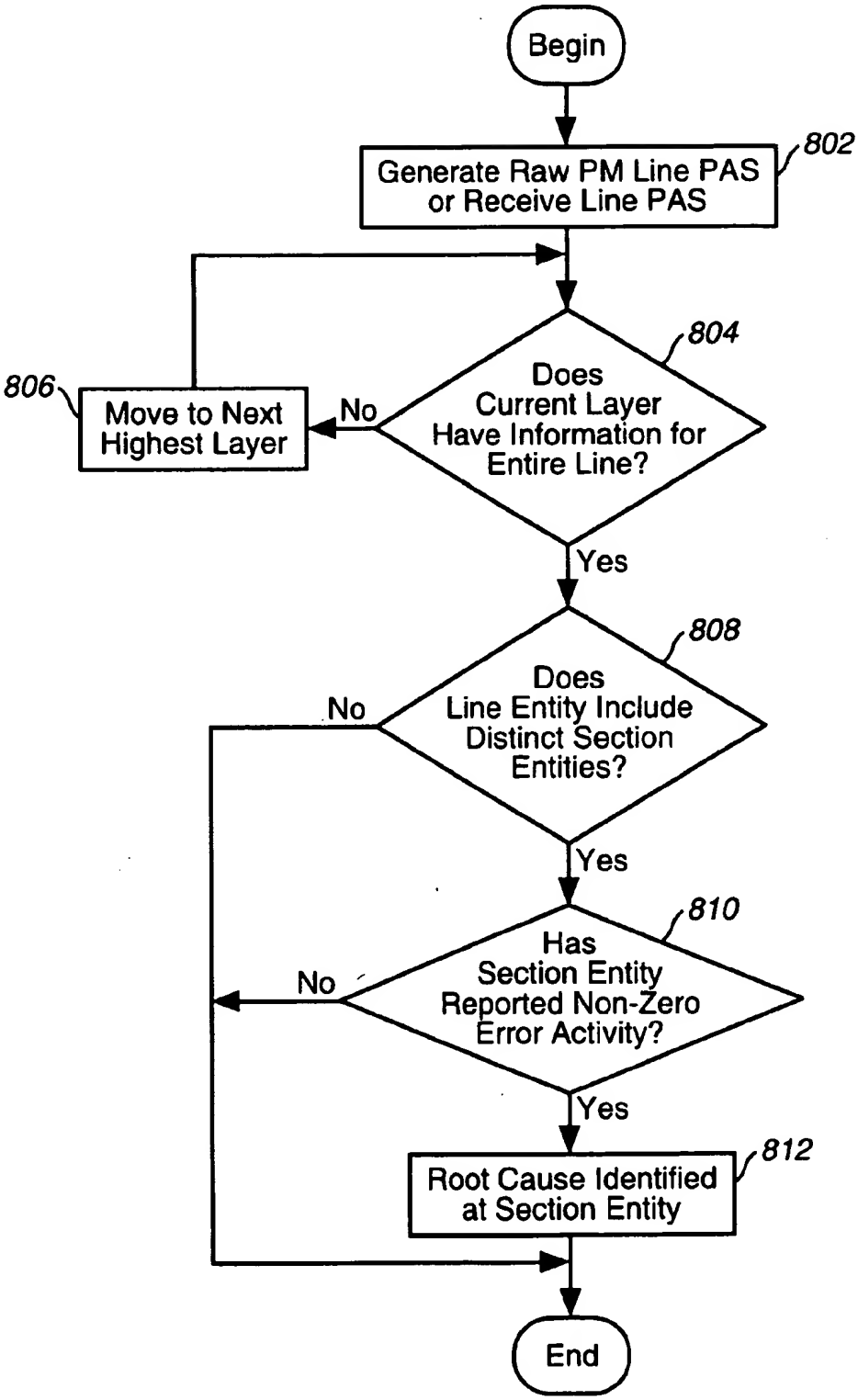

Begin
Generate Raw PM Line PAS or Receive Line PAS
802
Does Current Layer Have Information for Entire Line?
804
No
Move to Next Highest Layer
806
Yes
Does Line Entity Include Distinct Section Entities?
808
No
Yes
Has Section Entity Reported Non-Zero Error Activity?
810
No
Yes
Root Cause Identified at Section Entity
812
End

FIG. 8

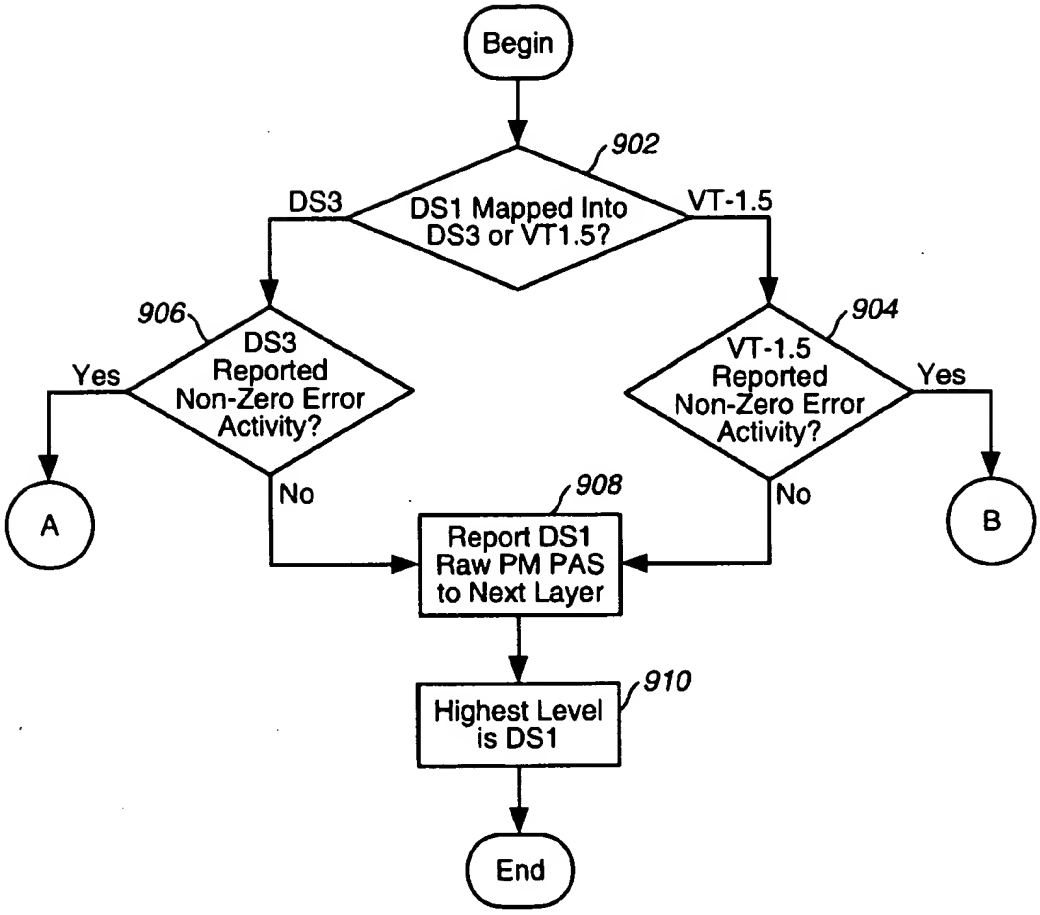

Begin
902
DS1 Mapped Into DS3 or VT1.5?
DS3
VT-1.5
906
DS3 Reported Non-Zero Error Activity?
904
VT-1.5 Reported Non-Zero Error Activity?
Yes
Yes
No
No
A
B
908
Report DS1 Raw PM PAS to Next Layer
910
Highest Level is DS1
End

FIG. 9A

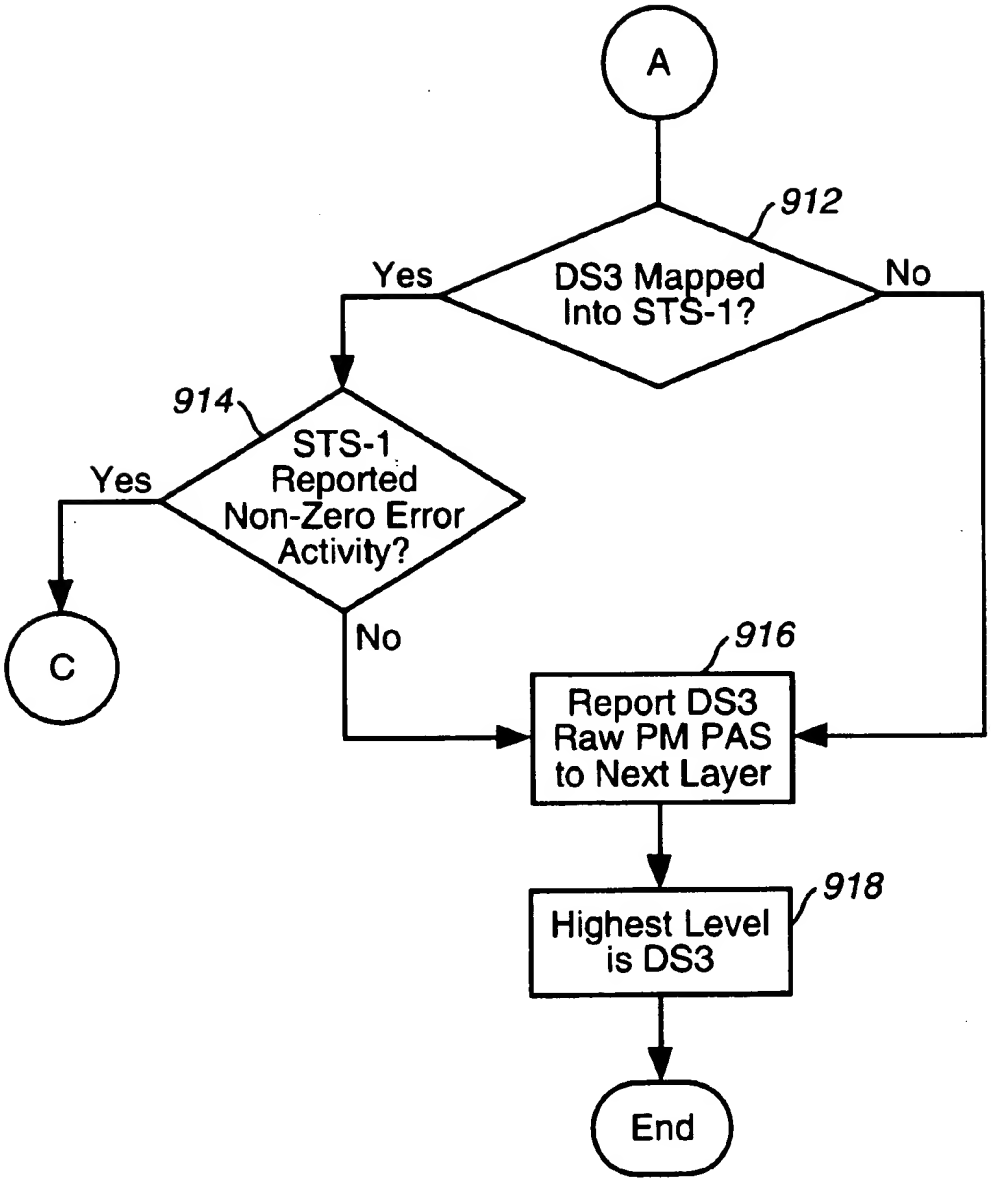

A
912
DS3 Mapped Into STS-1?
Yes
No
914
STS-1 Reported Non-Zero Error Activity?
Yes
No
C
916
Report DS3 Raw PM PAS to Next Layer
918
Highest Level is DS3
End

FIG. 9B

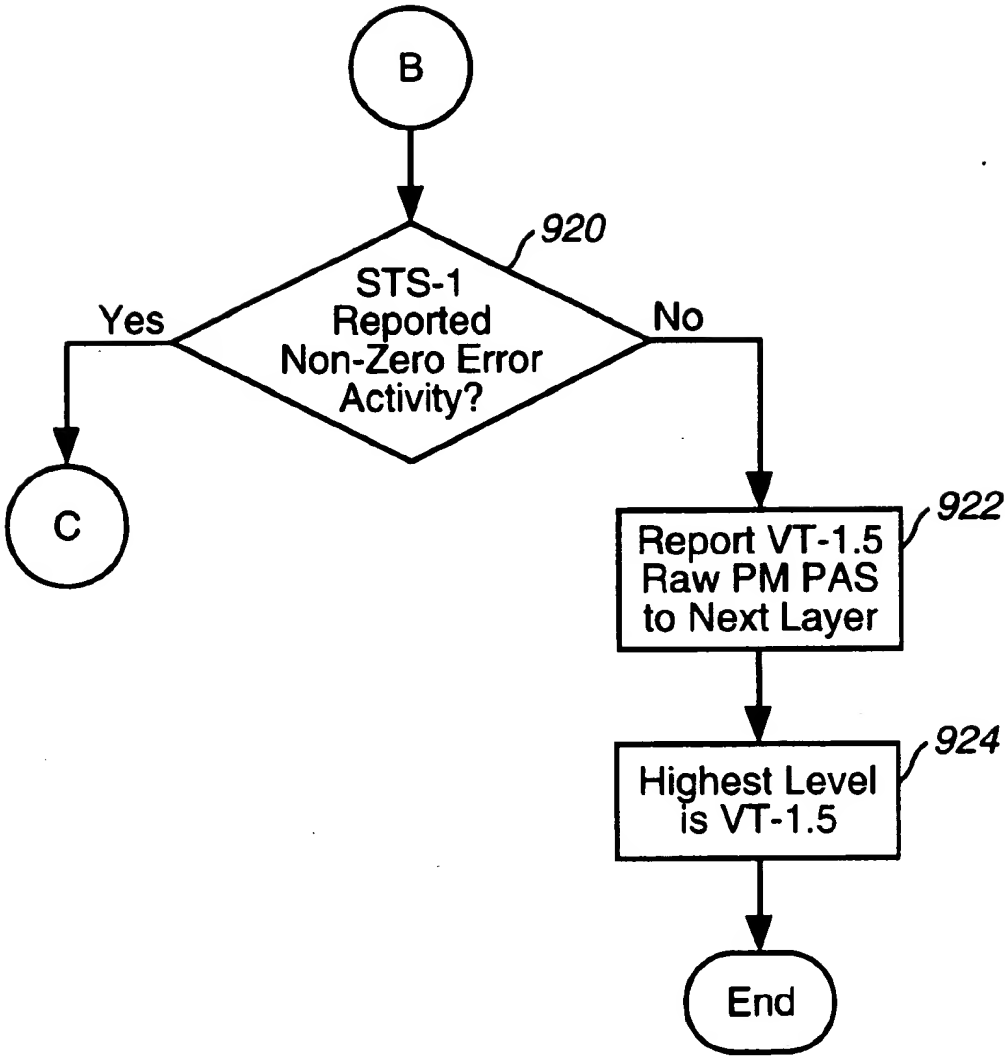

B
920
STS-1 Reported Non-Zero Error Activity?
Yes
No
C
Report VT-1.5 Raw PM PAS to Next Layer
922
Highest Level is VT-1.5
924
End

FIG. 9C

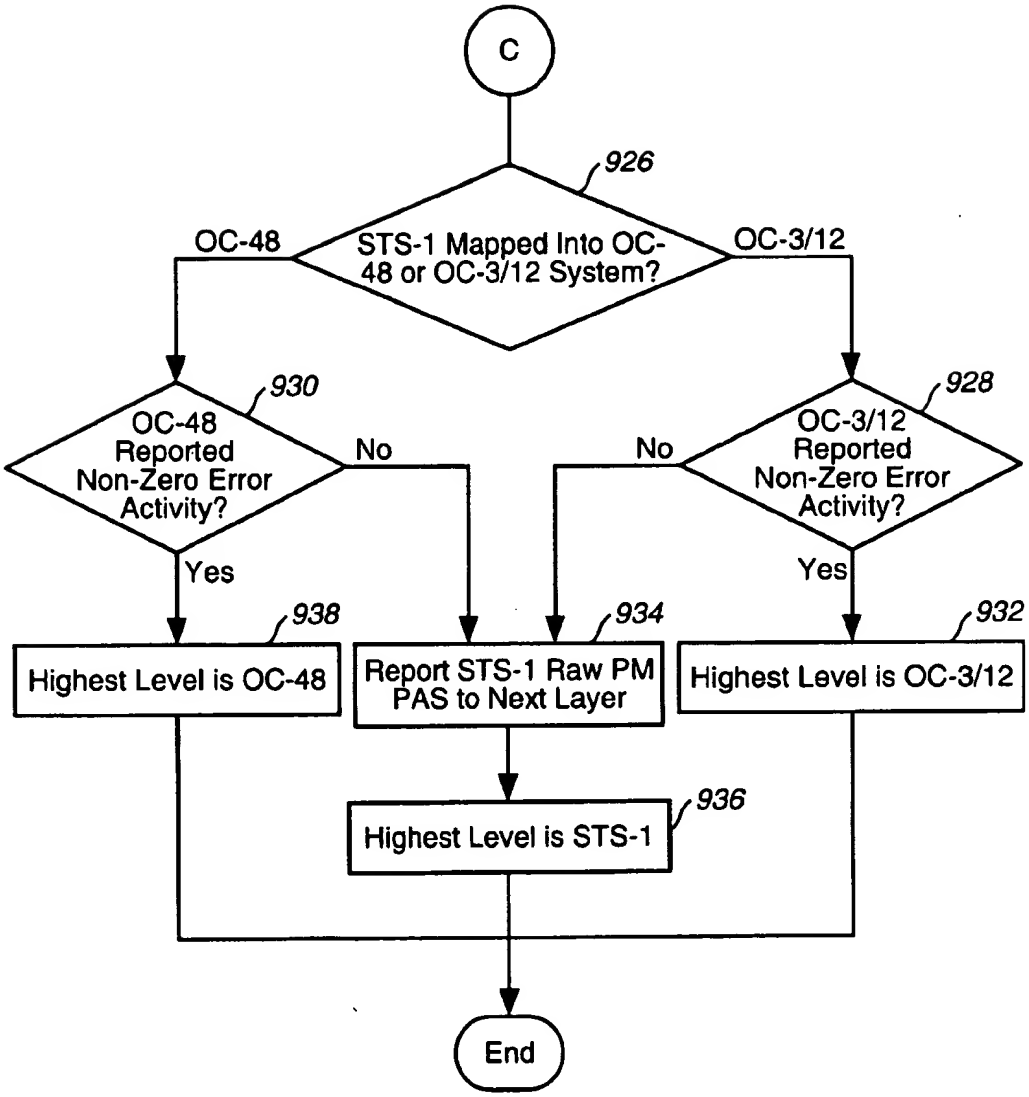

C
926
STS-1 Mapped Into OC-48 or OC-3/12 System?
OC-48
OC-3/12
930
OC-48 Reported Non-Zero Error Activity?
928
OC-3/12 Reported Non-Zero Error Activity?
No
No
Yes
Yes
938
934
932
Highest Level is OC-48
Report STS-1 Raw PM PAS to Next Layer
Highest Level is OC-3/12
936
Highest Level is STS-1
End

FIG. 9D

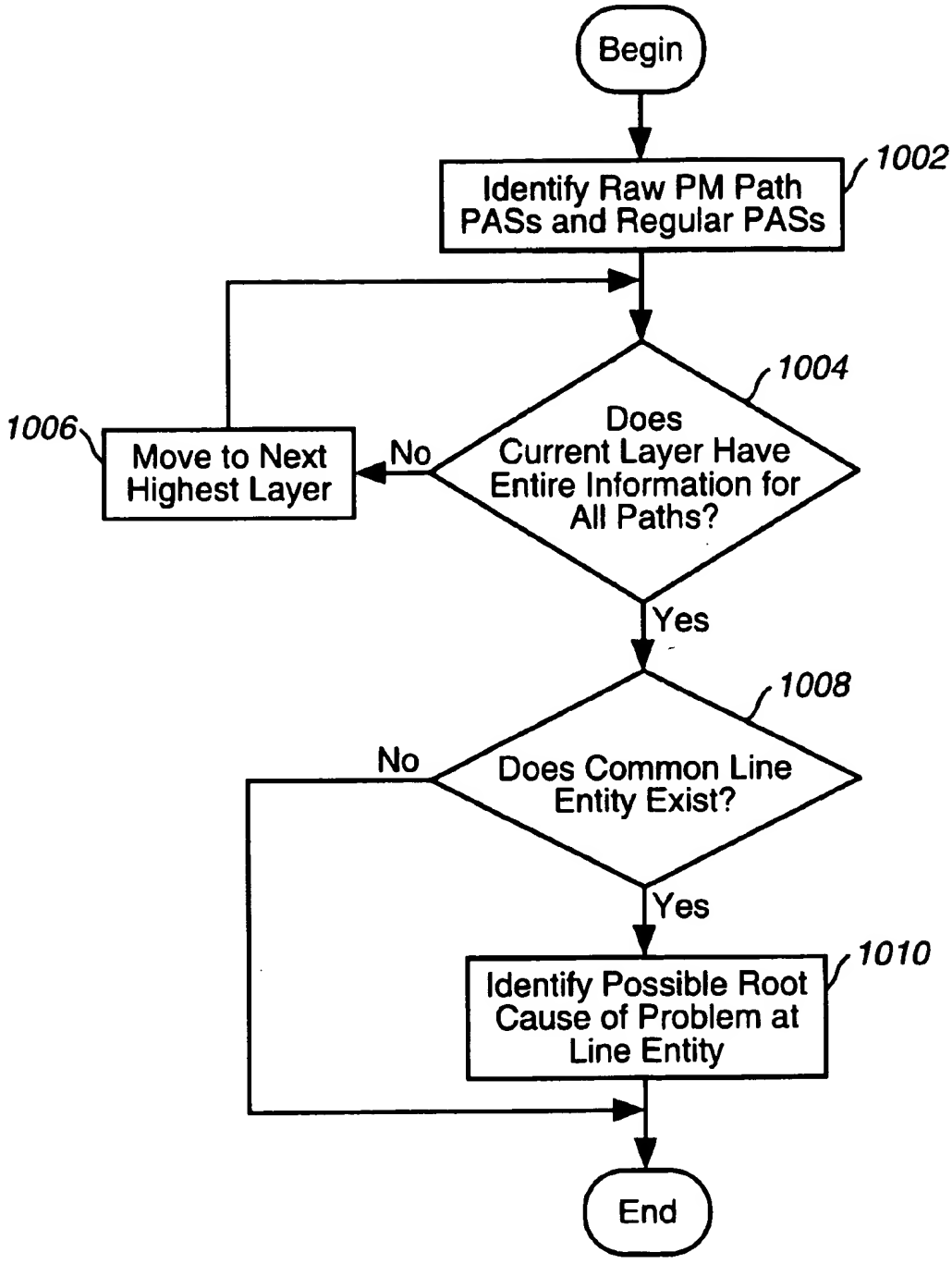

Begin
Identify Raw PM Path PASs and Regular PASs
1002
Does Current Layer Have Entire Information for All Paths?
1004
No
Move to Next Highest Layer
1006
Yes
Does Common Line Entity Exist?
1008
No
Yes
Identify Possible Root Cause of Problem at Line Entity
1010
End

FIG. 10

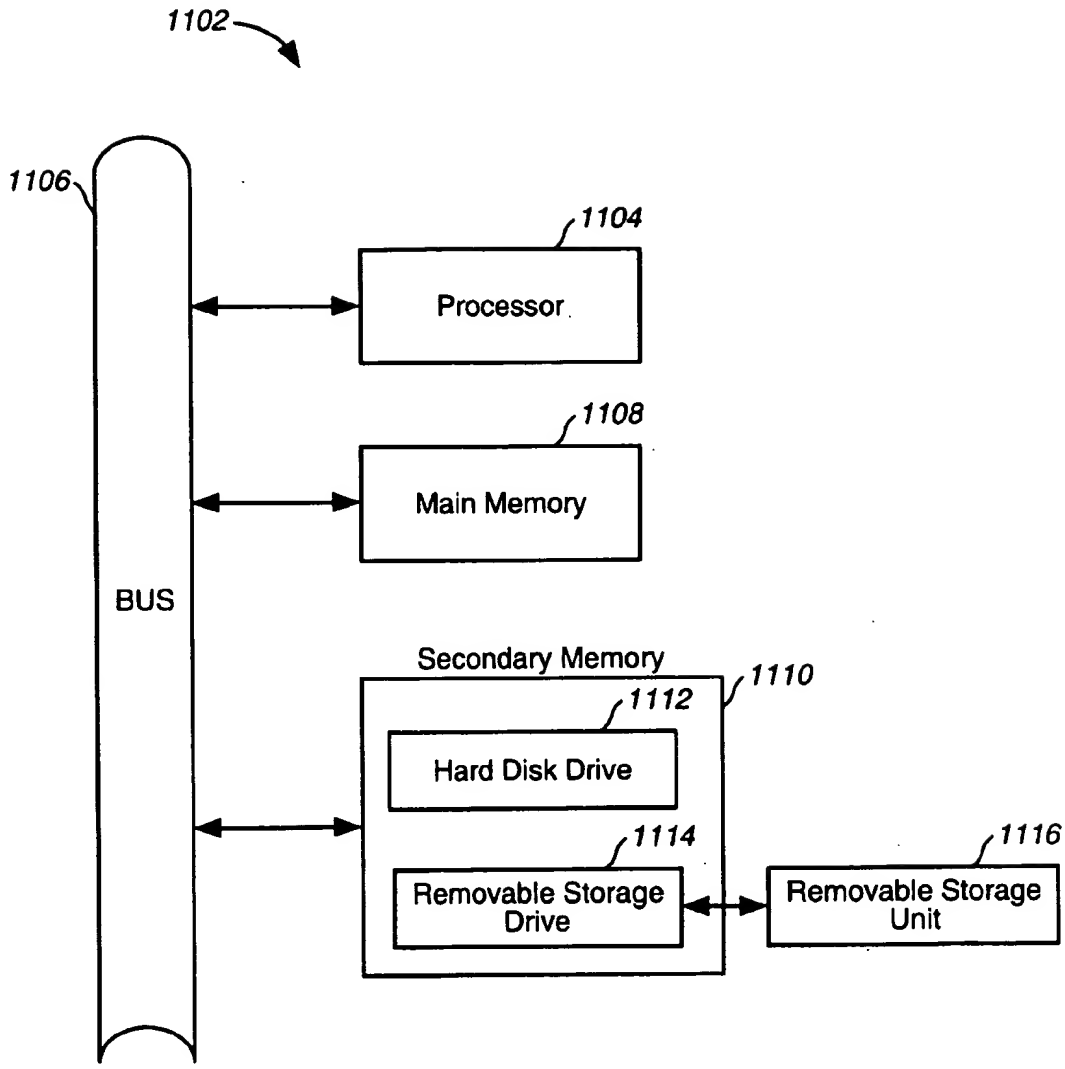

1102
1106
BUS
1104
Processor
1108
Main Memory
Secondary Memory
1110
1112
Hard Disk Drive
1114
Removable Storage Drive
1116
Removable Storage Unit

FIG. 11

SYSTEM AND METHOD FOR UNREPORTED ROOT CAUSE ANALYSIS

CROSS-REFERENCE TO OTHER APPLICATIONS

The following applications of common assignee contain some common disclosure:

U.S. Patent Application entitled "System and Method for Identifying the Technique Used for Far-End Performance Monitoring of a DS1 at a Customer Service Unit," Ser. No. 08/671,028, filed Jun. 25, 1996.

U.S. Patent Application entitled "System and Method for Formatting Performance Data In a Telecommunications System," Ser. No. 08/670,905, filed Jun. 26, 1996.

U.S. Patent Application entitled "System and Method for Reported Root Cause Analysis," Ser. No. 08/670,844, filed Jun. 28, 1996.

U.S. Patent Application entitled "Enhanced Correlated Problem Alert Signals," Ser. No. 08/670,848, filed Jun. 28, 1996.

U.S. Patent Application entitled "Correlated Problem Alert Signals," Ser. No. 08/673,271, filed Jun. 28, 1996.

U.S. Patent Application entitled "Raw Performance Monitor Correlated Problem Alert Signals," Ser. No. 08/670,847, filed Jun. 28, 1996.

U.S. Patent Application entitled "System and Method for Reported Trouble Isolation," Ser. No. 08/672,812, filed Jun. 28, 1996.

U.S. Patent Application entitled "System and Method for Unreported Trouble Isolation," Ser. No. 08/672,513, filed Jun. 28, 1996.

U.S. Patent Application entitled "System and Method for Monitoring Point Identification," Ser. No. 08/672,512, filed Jun. 28, 1996.

U.S. Patent Application entitled "System and Method for End-to-End Threshold Setting," Ser. No. 08/670,845, filed Jun. 28, 1996.

U.S. Patent Application entitled "System and Method for Monitoring Point Activation," Ser. No. 08/672,356, filed Jun. 28, 1996.

U.S. Patent Application entitled "System and Method for Tracking and Monitoring Network Elements," Ser. No. 08/671,029, filed Jun. 25, 1996.

The above-listed applications are incorporated herein by reference in their entireties.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates generally to network management systems, and more specifically is directed toward the determination of a root cause of error activity at one or more signal transport levels.

2. Related Art

The present application is a continuation of Application Ser. No. 08/668,516 filed Jun. 28, 1996 Entitled "System and Method for Unreported Root Cause Analysis".

Telecommunication service providers (e.g., MCI Telecommunications Corporation) provide a wide range of services to their customers. These services range from the transport of a standard 64 kbit/s voice channel (i.e., DS0 channel) to the transport of higher rate digital data services (e.g., video). Both voice channels and digital data services are transported over the network via a hierarchy of digital signal transport levels. For example, in a conventional digital signal hierarchy 24 DS0 channels are mapped into a DS1 channel. In turn, 28 DS1 channels are mapped into a DS3 channel.

Routing of these DS1 and DS3 channels within a node of the network is performed by digital cross-connect systems. Digital cross-connect systems typically switch the channels at the DS1 and DS3 signal levels. Transmission of channels between nodes is typically provided via fiber-optic transmission systems. Fiber-optic transmission systems can multiplex a plurality of DS3 channels into a higher rate transmission over a single pair of fibers. In one example, signal formats for the fiber-optic transmission systems are defined by the manufacturer. These proprietary systems are referred to as asynchronous transmission systems.

Alternatively, a fiber-optic transmission system can implement the synchronous optical network (SONET) standard. The SONET standard defines a synchronous transport signal (STS) frame structure that includes overhead bytes and a synchronous payload envelope (SPE). One or more channels (e.g., DS1 and DS3 channels) can be mapped into a SPE. For example, a single DS3 channel can be mapped into a STS-1 frame. Alternatively, 28 DS1 channels can be mapped into virtual tributaries (VTs) within the STS-1 frame.

Various STS-1 frames can be concatenated to produce higher rate SONET signals. For example, a STS-12 signal includes 12 STS-1 frames, while a STS-48 signal includes 48 STS-1 frames. Finally, after an STS signal is converted from electrical to optical, it is known as an optical carrier (OC) signal (e.g., OC-12 and OC-48).

An end-to-end path of a provisioned channel within a network typically traverses a plurality of nodes. This provisioned channel is carried over transmission facilities that operate at various rates in the digital signal hierarchy. For example, a provisioned DS1 channel may exist as part of a DS3, VT1.5, STS-1, STS-12, OC-12, and OC-48 signal along parts of the end-to-end path. This results due to the multiplexing and demultiplexing functions at each of the nodes.

One of the goals of a network management system is to monitor the performance of the provisioned channel. Performance of the provisioned channel can include various measures. One measure is the unavailability of the provisioned channel. Unavailability is generally defined as the amount (or fraction) of time that a channel is not operational. Various causes such as cable cuts can lead to channel downtime. Network responses to channel downtime can include automatic protection switching or various restoration procedures (e.g., digital cross-connect distributed restoration).

Although unavailability is a major performance measure from a customer's standpoint, other performance measures can also be critical. For example, if a customer desires a digital data service for the transmission of financial data, the number of errored seconds or severely errored seconds may be a concern.

In conventional network management systems, performance monitoring is accomplished in piecewise fashion. For example, consider a provisioned channel that traverses an end-to-end path comprising asynchronous transmission systems and SONET transmission systems. Performance monitoring information for these two types of transmission systems is typically maintained in separate databases. Moreover, the various types of transmission systems may be provided by multiple vendors. Each of these vendors may define their own separate performance monitoring process. For example, the vendor-controlled process may define the types of data that are retrieved from or reported by the individual network elements.

In this environment, comprehensive performance monitoring analysis is difficult to accomplish. What is needed is a network management system that can monitor provisioned channels at various points of the end-to-end path and identify the root cause of problems that lead to observable error activity. This capability allows a service provider to efficiently resolve problems that lead to degradation of network performance.

SUMMARY OF THE INVENTION

The present invention satisfies the above mentioned needs by providing a comprehensive network management system that can isolate a root cause of a problem in the network. In a first embodiment of the present invention, the root cause analysis operates on problem alert signals (PASs) generated by monitoring points in the network. One example of a problem alert signal is a threshold crossing alert. A threshold crossing alert is generated when a monitored performance parameter exceeds a predefined threshold.

In a second embodiment of the present invention, the root cause analysis operates on reported error activity. Statistical analysis can be used to identify facility operating conditions that could lead to a significant network problem. For example, the network facility could be operating at a point near the tolerance levels. Intermittent errors could therefore result due to temporary excursions beyond the tolerance thresholds. If a statistical analysis identifies a potential problem, a raw performance monitoring PAS is generated.

In the present invention, root cause analysis seeks to identify sources of problems identified by a plurality of PASs that are visible to a layer in a network management system. Analysis of the plurality of PASs include various correlation processes. In one method, path PASs are correlated to line PASs. In this manner, error activity identified on a provisioned channel can be isolated to a particular line entity of the network. Further, in a second method of root cause analysis, line PASs are correlated to section PASs. This second correlation process allows error activity identified on a line entity to be isolated to a particular section entity within the line entity. As part of this general correlation process, the root cause analysis correlates error activity between signal levels in the signal transport hierarchy. In this method of analysis, the highest transport level experiencing error activity is identified. In this manner, the network facilities that are the source of the problem can be identified.

An additional method of root cause analysis also correlates error activity between path entities. Error activity on various path entities may be caused by a common facility problem that is not detected by line entities within the path entity. Identification of common line entities within the various path entities eliminates redundant root cause analysis processing of the individual path entities.

The foregoing and other features and advantages of the invention will be apparent from the following, more particular description of a preferred embodiment of the invention, as illustrated in the accompanying drawings.

BRIEF DESCRIPTION OF THE FIGURES

In the drawings, like reference numbers indicate identical or functionally similar elements. Additionally the left-most digit of a reference number identifies the drawing in which the reference number first appears.

FIG. **1** illustrates the layers in a network management system.

FIG. **2** illustrates an exemplary circuit topology.

FIGS. **3** and **7** illustrate flow charts of the correlation process between path and line entities.

FIGS. **4** and **8** illustrate flow charts of the correlation process between line and section entities.

FIGS. **5A–5D** and **9A–9D** illustrate flow charts of the correlation between levels in the digital signal transport hierarchy.

FIGS. **6** and **10** illustrate flow charts of the correlation between path entities.

FIG. **11** illustrates a block diagram of a computer useful for implementing elements of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The operation and administration of a service provider's network is becoming increasingly complex. Network elements continue to evolve in support of the provision of a wider range of services. The overriding goal of network management is to ensure that all aspects of the network are operating according to both the service provider's design and the customer's expectations.

A general open-ended framework is defined by the International Telecommunications Union (ITU) Telecommunications Management Network (TMN) standard. The TMN standard defines a layered framework for a service provider to implement its own network management process.

FIG. **1** illustrates a network management system **100** that includes five layers **110, 120, 130, 140** and **150**. Layer **150** is designated as the network element layer (NEL). The NEL is a physical layer that includes the various network elements (e.g., asynchronous systems, SONET systems, etc.) used in the transport and routing of network traffic (e.g., DS1, DS3, OC-N, etc.). Each network element **151–156** in NEL **150** can be designed to provide performance monitoring, alarm and status information to the higher layers in network management system **100**. In particular, network elements **151–156** are connected to one of the element managers **141–143** in element management layer (EML) **140**. For example, network elements **151** and **152** are connected to element manager **141**. In this manner, each network element manager **141–143** controls a portion of the physical network embodied in NEL **150**.

Element managers **141–143** can retrieve information from network elements **151–156** periodically or upon a user request. Alternatively, network elements **151–156** can be programmed to provide element managers **141–143** with a predefined subset of network management information at predefined time intervals. The domain of an element manager **141–143** can be defined by a vendor's equipment. In some situations, the domain of an element manager **141–143** is dictated by the geography in which network elements **151–156** reside.

After network management information is acquired by element managers **141–143** from network elements **151–156**, it is forwarded to network management layer (NML) **130**. NML **130** comprises network manager **131**. Network manager **131** is logically shown as a single entity. In implementation, network manager **131** can comprise one or more sites. For example, multiple service centers (not shown) can exist at different parts of the country (e.g., east coast and west coast). In combination, these national-level service centers combine to provide total visibility of the physical network in NEL **150**. Network manager **131** can also be split among services and/or network elements. For

example, in one embodiment, a first network manager is dedicated to asynchronous parts of the network, a second network manager is dedicated to DS1, DS3 and VT-n traffic, and a third network manager is dedicated to STS-n and OC-n traffic.

Generally, the logical entity identified as network manager **131** is a resource that is accessed by applications in service management layer (SML) **120**. In FIG. **1**, SML **120** is shown to include five applications **121–125**. Specifically, SML **120** includes provisioning application **121**, accounting/billing application **122**, security application **123**, network performance application **124**, and fault management application **125**. This listing of applications is provided without limitation. Any other application that utilizes network management data stored within NEL **150** can also be included. Note that elements of applications **121–125** also reside within EML **140** and NML **130**.

Provisioning application **121** provides a customer interface for the provisioning of various services. For example, a customer can indicate a desire for a DS1 digital data service between network element **151** and network element **155**. Upon receipt of this customer request, provisioning application **121** relays the provisioning commands to network manager **131**. Network manager **131** then communicates with element managers **141, 143** and any other element managers that control a part of the end-to-end path to set up the DS1 connection from network elements **151–155**.

Applications **122–125** can similarly support a customer interface by providing access to billing information, security information, performance information and fault management information, respectively. Each of these applications also access the resources that are stored within network manager **131**.

Finally, network management system **100** also includes business management layer (BML) **110**. BML **100** includes logical entity **111**. Logical entity **111** represents the general corporate policy of network management system **100**. Corporate policy **111** dictates the general business and contractual arrangements of the service provider.

Having identified the various layers in network management system **100**, a system and method for root cause analysis is now described. Root cause analysis is generally concerned with the identification of a source of a problem in the network. Problems in the network may or may not involve actual system downtime. In other words, problems in the network may manifest themselves as degradations in system performance. An example of performance degradation includes an increase in the bit error rate (BER). Bit errors are typically measured in terms of errored seconds (ESs) and severely errored seconds (SESs). An unacceptable increase in the BER of the provisioned channel may prove unsatisfactory to the customer. In many instances, customer expectations of performance of a provisioned channel are defined by the requirements contained within a service contract. The service contract may correlate system performance to the tariffing structure. If the number of ESs, SESs or unavailability of the service becomes excessive, customer rebates may be in order.

In a competitive business climate, it is desirable for a service provider to quickly identify and repair problems leading to system downtime or degradation. If a root cause of a problem cannot be pinpointed, it will continue to affect system performance and a customer's perceptions. The present invention provides a system and method for identifying the root cause of network problems using a comprehensive approach. This comprehensive approach analyzes the information stored in one or more layers of network management system **100**.

In a first embodiment, root cause analysis is operative on error activity that is reported from monitoring points that are associated with network elements **151–156**. Monitoring points are described in greater detail in related applications entitled "System and Method for Monitoring Point Identification," Ser. No. 08/672,512, filed Jun. 28, 1996; "System and Method for End-to-End Threshold Setting," Ser. No. 08/670,845, filed Jun. 28, 1996; and "System and Method for Monitoring Point Activation," Ser. No. 08/672,356, filed Jun. 28, 1996.

Generally, monitoring points are labeled as either primary monitoring points or secondary monitoring points. A basic monitoring point strategy for a generic end-to-end path includes the placement of monitoring points nearest to the facility end points. Monitoring points nearest to the facility end points are designated as primary monitoring points (PMPs). A facility end point can be thought of as a generic customer termination point (e.g., handoff point to a business, local exchange carrier, etc.). In the context of FIG. **2**, PMPs can be associated with source **202** and destination **204**.

In addition to the PMPs, a provisioned channel may also include SMPs. SMPs are intermediate performance monitoring data collection points. SMPs allow network management system **100** to isolate a network problem by providing performance monitoring information at intermediate sections of the end-to-end path.

Over a period of time, a monitoring point associated with a network element may observe an excessive number of ESs on a received channel. If the monitoring point determines that the error activity is significant, a problem alert signal (PAS) is reported to one of element managers **141–143**. Note that any type of statistical analysis can be used by the monitoring point to determine whether to report a PAS to an element manager **141–143**. For example, the monitoring point could determine whether a number of ESs exceeds a predefined threshold. In the remainder of the description, PASs are used to describe the general class of reported error activity.

Note that a monitoring point can generate a PAS based upon error activity measured at section, line, and path terminating points. FIG. **2** illustrates section, line and path entities in an exemplary channel (e.g., DS1, DS3, VT-n, STS-1, STS-3c, STS-12c, etc.) provisioned between source **202** and destination **204**. In this example, the channel originates at source **202**, traverses multiplexer **210**, regenerators **220** and **230**, and cross-connect **240**, and finally terminates at destination **204**. Each network element **202, 204, 210, 220, 230** and **240** inserts and extracts overhead information. In the SONET context, section and line overhead information is contained within the transport overhead portion of a synchronous transport signal (STS) frame (not shown). Path overhead information, on the other hand, is contained within the synchronous payload envelope (SPE) information payload. Note that the terms section, line and path are used without limitation. As would be apparent to one of ordinary skill in the relevant art, the root cause analysis described below could also be extended to other network transmission standards having analogous network sectionalization.

In the following description, section, line and path entities are used to refer to the portions of the network that insert and extract section, line and path overhead bytes, respectively. For example, the OC-N link between regenerators **220** and **230** define a section entity. In the transmission from regen-

erator **220** to regenerator **230**, regenerator **220** inserts the section overhead bytes into the STS-N frame, performs an electrical-to-optical conversion of the STS-N signal, and transmits the OC-N signal to regenerator **230**. Regenerator **230** then receives the OC-N signal, performs an optical-to-electrical conversion and extracts the section overhead information. Regenerator **230** can use the extracted section overhead information to determine the error performance of the transmission from regenerator **220**. For example, errors may have been created by a problem with the optical fiber, a problem with a fiber-optic connector, etc. A monitoring point associated with regenerator **230** tracks this error performance over a monitoring period and reports the accumulated results to an element manager **141–143**. Note that regenerators **220** and **230** extract only the section overhead information. For this reason, the span between regenerators **220** and **230** define section entity **252** not line or path entities.

Next, consider the span between multiplexer **210** and cross-connect **240**. In this span, multiplexer **210** and cross-connect **240** insert and extract both line and section overhead information. Note that only one direction of the two-way communication is illustrated. As shown, the insertion and extraction of line overhead information defines line entity **257**. Line entity **257** includes section entities **252–254**. Finally, consider source **202** and destination **204**. These elements insert and extract path overhead information, thereby defining path entity **259**. Path entity **259** includes section entities **251–255** and line entities **256–258**.

In considering the network as a whole, each channel provisioned over a plurality of network elements defines its own section, line and path entities. Monitoring points associated with these network elements can monitor error activity for section, line or path entities. Based upon the monitored error activity, a monitoring point can determine whether a PAS should be generated. This PAS is sent to an element manager **141–143**. The PAS can also be forwarded to higher layers in network management system **100**.

During a single monitoring period, monitoring points for the various provisioned channels in the network can report section, line and path PASs. Each layer in network management system **100** can analyze the reported PASs to determine whether one or more root causes exist. The root cause analysis can simultaneously utilize one or more of the following methods of PAS analysis.

A first method of analysis is based upon the relationship between path entities and line entities. FIG. **3** illustrates a flow chart of the path and line entity correlation process. The process begins at step **302** where a layer in network management system **100** receives a path PAS. Assume that a monitoring point associated with destination **204** has reported a path PAS to element manager **143**. Element manager **143** then determines, at step **304**, whether it has enough information to identify the root cause of the network problem.

Recall that each element manager **141–143** has access to network management information received from a subset of network elements **151–156**. If the reported PAS was caused by a problem outside of an element manager's domain, then that particular element manager cannot isolate the problem. Various sequences of decisions are used by each element manager **141–143** to determine if the problem can be isolated.

For example, consider the reported performance parameter of severely errored seconds (SESs). SESs can be classified into two types, line SESs (SESL) and path SESs (SESP). If a PAS is generated based upon an excessive number of SESLs, then the element manager knows that the problem is local. Assuming that both ends of the line reside in the element manager's domain, the element manager can conclude that the network problem can be isolated.

If a PAS is triggered based upon an excessive number of SESPs, then the element manager knows that the network problem may not necessarily reside in the element manager's domain. An additional determination must be made as to whether the originating and terminating network elements reside in the element manager's domain. If both reside in the element manager's domain, then the element manager knows that it can isolate the network problem.

As would be apparent to one of ordinary skill in the relevant art, implementation dependent decision trees can be designed to determine whether a root cause of a network problem can be isolated based upon a specific type of PAS. If an element manager **141–143** determines that it does not have enough information to identify the root cause of the network problem, then the root cause analysis must be performed by the next highest layer in network management system **100** (i.e., NML **130**). This is illustrated by step **306**. Note that network manager **131** of NML **130** begins the isolation process as soon as a PAS is received from one of element managers **141–143**.

Once control passes to NML **130**, network manager **131** similarly determines whether it has enough information to isolate the problem. As noted above, in one embodiment multiple network managers are used. In this case, root cause analysis is performed by an application in SML **120** using the resources contained in the multiple network managers.

In the following description, assume that element manager **143** determines, at step **304**, that it has enough information to identify the root cause. Next, element manager **143** determines, at step **308**, whether a distinct line entity exists for the path entity. In other words, element manager **143** determines whether the path entity includes more than one line entity. If a path entity includes only one line entity, then the line and path overhead information inserted at source **202** is extracted at the same point. In the context of FIG. **2**, this scenario would arise if multiplexer **210**, regenerators **220** and **230**, and cross-connect **240** did not exist.

If element manager **143** determines, at step **308**, that the path entity does not include distinct line entities, then the path-line correlation process of FIG. **3** ends. In this case, the root cause analysis cannot be further narrowed to a part of the path entity. However, if element manager **143** determines, at step **308**, that the path entity does include distinct line entities, then element manager **143** next determines, at step **310**, whether a line entity within the path entity has reported a corresponding PAS.

If none of the line entities within the path entity has reported a corresponding PAS, then the path-line correlation process ends. This results since the reported PASs within the current monitoring period does not contain enough line entity information to further identify the root cause of the path PAS. In one example, the root cause of the path PAS may not have been identified by monitoring points associated with the line entities. In another example, the monitoring points associated with the line entities may not have been activated. Subsequent activation of the monitoring points will allow further root cause analysis in a later monitoring period.

Finally, if element manager **143** determines, at step **310**, that a line entity has reported a corresponding PAS, then the

root cause of the network problem is narrowed to a particular line entity. Additional root cause analysis then proceeds at step **312** to further identify the root cause of the problem within the identified line entity. For example, the root cause could reside in a section entity within the line entity. Note that more than one line entity within a path entity can report a corresponding PAS. For example, errors within line entities **256** and **257** of FIG. **2** could both be sufficient to trigger the reporting of a PAS.

FIG. **4** illustrates a second method of root cause analysis that is based upon the correlation of PASs reported by line entities and section entities. The line-section correlation process begins at step **402** where a layer in network management system **100** receives a line PAS. In the following discussion, assume that a monitoring point associated with cross-connect **240** has reported a line PAS to element manager **143**. Element manager **143** then determines, at step **404**, whether it has enough information to identify the root cause of the network problem. For example, if a line PAS is generated by a monitoring point associated with cross-connect **240** of line entity **257**, element manager **143** may determine that multiplexer **210** and regenerator **220** are in another element manager's domain. In this case, root cause analysis of the line PAS is performed at a higher layer in network management system **100** that has access to information for line entity **257**.

If element manager **143** determines, at step **404**, that it has enough information to identify the root cause, then element manager **143** determines, at step **408**, whether a distinct section entity exists for the line entity. In the example of line entity **257**, distinct section entities **252–254** would exist.

If element manager **143** determines, at step **408**, that the line entity does not include distinct section entities, then the line-section correlation process of FIG. **4** ends. In this case, the root cause analysis cannot be further narrowed to a part of the line entity. However, if element manager **143** determines, at step **408**, that the line entity does include distinct section entities, then element manager **143** next determines, at step **410**, whether a section entity within the line entity has reported a corresponding PAS.

If none of the section entities within the line entity has reported a corresponding PAS, then the line-section correlation process ends. This results since the reported PASs within the current monitoring period does not contain enough section entity information to further identify the root cause of the line PAS. In a similar manner to the line-section correlation process described above, the path-line correlation process could result if the monitoring points associated with the section entities have not been activated.

Finally, if element manager **143** determines, at step **410**, that a section entity has reported a corresponding PAS, then the root cause of the network problem is narrowed to the particular section entity. Since the section entity is the lowest level of granularity, the root cause analysis is complete. Thus, at step **412**, the section entity is identified as the root cause of the network problem. Again, note that more than one section entity within a line entity can report a PAS.

As described above, a function of the root cause analysis is to correlate PASs. Path PASs can be correlated with line PASs and line PASs can be further correlated to section PASs. As part of this general correlation process a layer in network management system **100** correlates PASs between various signal levels in the transport hierarchy. Generally, when error activity is detected at a particular digital transport level, the correlation of that error activity to other error activity within the digital transport level hierarchy is not a simple matter. For example, error activity detected at the DS3 level may not be detected at the STS-48 level. This may result due to the insufficient granularity of the error detection at the higher STS-48 level. An error at the STS-48 level may affect some or all of the lower transport levels within the STS-48 signal depending on the severity and the distribution of the error event. For example, bursty errors may affect only some of the lower transport levels while a continuous error may affect all lower transport levels. For this reason, performance monitoring data is collected at different hierarchial signal transport levels and error activity is correlated between the different signal transport levels.

In this correlation process, the highest rate in the transport signal hierarchy experiencing simultaneous error activity is identified. FIGS. **5A–5D** illustrate this correlation process of identifying the highest signal transport level that experiences simultaneous error activity. In the following description, assume that element manager **141** has received a DS1 path PAS from a network element in its domain.

First, at step **502**, element manager **141** determines whether the DS1 channel is mapped into a DS3 channel or into a VT-1.5 channel. If the DS1 channel is mapped into a DS3 channel, the process continues at step **506**. At step **506**, element manager **141** determines whether the DS3 in which the DS1 is mapped has reported a PAS. In other words, element manager **141** determines whether the DS3 in which the DS1 is mapped has simultaneous error activity occurring.

In a similar manner to step **506**, step **508** is invoked if element manager **141** determines, at step **502**, that the DS1 is mapped into a VT-1.5 channel. At step **308**, element manager **141** determines whether the VT-1.5 in which the DS1 is mapped has reported a PAS. Again, element manager **141** determines whether the VT-1.5 has simultaneous error activity occurring.

If the determination at either step **504** or step **506** determines that the VT-1.5 or DS3, respectively, has not reported a PAS, then element manager 141 reports the DS1 path PAS to network manager **131** in NML **130**. Next, at step **510**, the highest transport level is identified as a DS1 and the process ends.

Returning to step **506**, if the DS3 in which the DS1 is mapped does report a PAS, the process continues to step **512** of FIG. **5B**. At step **512**, element manager **141** determines whether the DS3 is mapped into a STS-1. If the DS3 is not mapped into an STS-1, the DS3 PAS is reported to network manager **131** at step **516**. Thereafter, the highest transport level is identified as a DS3. If element manager **141** determines, at step **314**, that the DS3 is mapped into an STS-1, element manager **141** then determines whether the STS-1 has reported a PAS. If a STS-1 PAS was not reported, the DS3 PAS is reported to network manager **131**.

Returning to step **504**, if the VT-1.5 in which the DS1 is mapped does report a PAS, the process continues to step **520** of FIG. **5C**. At step **520**, element manager **141** determines whether the STS-1 in which the VT-1.5 is mapped has reported a PAS. Here, no determination is made as to whether the VT-1.5 is mapped into a STS-1. This results because a VT-1.5 channel cannot exist in the network independently of a STS-1 channel. If the associated STS-1 in which the VT-1.5 is mapped has not reported a PAS, the VT-1.5 PAS is reported to network manager **131** at step **522**. Next, the highest transport level is identified as a VT-1.5 channel at step **524**.

If element manager **141** determines at either step **514** or step **520** that a STS-1 has reported a PAS, the process

continues at step **526** of FIG. **5**D. At step **526**, element manager **141** determines whether the STS-1 is mapped into an OC-48 system or an OC-3/12 system. An OC-48 system is generally used to transport STS-1s between two nodes in the network. An OC-3 or OC-12 system, on the other hand, is generally used to transport STS-1s between network elements within a particular node. For example, an OC-3 or OC-12 fiber optic link could be used to transport STS-1s between an OC-48 line terminating equipment (LTE) and a broadband digital cross-connect system (BBDCS).

If element manager **141** determines at step **526** that the STS-1 is mapped into an OC-3/12 system, element manager **141** then determines, at step **328**, whether the OC-3/12 system has reported a PAS. If the OC-3/12 system has reported a PAS, the highest transport level is identified as a OC-3/12 at step **532**. Conversely, if the OC-3/12 system has not reported a PAS, a STS-1 PAS is reported to network manager **131** at step **534**. Next, the highest transport level is identified as a STS-1 at step **536**.

If element manager **141** determines at step **526** that the STS-1 is mapped into an OC-48 system, element manager **141** then determines, at step **530**, whether the OC-48 system has reported a PAS. If the OC-48 system has reported a PAS, the highest transport level is identified as a OC-48 at step **538**. Conversely, if the OC-48 system has not reported a PAS, a STS-1 PAS is reported to network manager **131** at step **534**. In this case, the highest transport level is identified as a STS-1 at step **536**.

As the flow chart of FIGS. **5**A–**5**D illustrate, this aspect of root cause analysis seeks to identify the highest transport level that is experiencing simultaneous error activity. Note that while all non-zero error activity is reported to the higher layers in network management system **100**, only the highest level path PAS is forwarded to NML **130**. This reduces the amount of trouble isolation processing that occurs at NML **130**. Generally, the identification of the highest level path PAS allows network management system **100** to identify the true source of the network error activity. Note also that the identification process of FIGS. **5**A–**5**D need not begin at the DS1 level. For example, the identification process could begin at step **512** after a DS3 PAS is reported.

Having described the general correlation process between signal transport levels, a simple example is provided with reference to FIG. **2**. In this example, assume that a STS-1 channel is provisioned between source **202** and destination **204**. Assume further that PMPs are associated with source **202** and destination **204** and SMPs are associated with multiplexer **210**, cross-connect **240**, and regenerators **220** and **230**. Both the PMPs and SMPs are activated. If errors are generated in any of network elements **202**, **210**, **220**, **230**, **240** in the end-to-end path, a STS-1 path PAS may be generated by a PMP associated with destination **204**. After receipt of a STS-1 path PAS, the correlation process continues at step **526** of FIG. **5**D. At step **526**, a layer in network management system **100** determines whether the STS-1 is mapped into an OC-48 or OC-3/12 system. This determination is based upon a retrieved topology of the provisioned channel. In this example, the STS-1 is mapped into the OC-N system that defines line entity **257**. Assuming that the OC-N system is an OC-48 system, the correlation process proceeds to step **530** where it is determined whether the OC-48 system has reported a PAS.

The determination at step **530** can be answered in the affirmative if the SMP that is associated with cross-connect **240**, reports a line PAS for the STS-48 signal. If this is the case, the STS-1 path PAS is correlated to the OC-48/STS-48 line PAS. At this point, the root cause analysis has narrowed the potential source of the error activity to line entity **257**. Further identification of the root cause of the problem is provided by an additional correlation between PASs for line entity **257** and PASs for section entities **252**–**254**.

Having described a correlation process between path, line and section PASs along the circuit topology of a single provisioned channel, a correlation process between independent path PASs is now provided. As described above, each path PAS that is received by a layer in network management system **100** could require independent root cause analysis consideration. Root cause analysis would generally seek to narrow the consideration from a path level to a line or section level using the correlation processes outlined above.

Note, however, that error activity detected for a path entity may not necessarily be identified at line or section entities. This results due to the error monitoring process for line and section entities. Consider the span defined by section entity **251** and line entity **256** of FIG. **2**. In this example, the line and section overhead bytes are inserted into the transport overhead part of a STS-1 frame at source **202**. These line and section overhead bytes are extracted by multiplexer **210**. Included within the line and section overhead bytes is a bit interleaved parity byte (BIP-8) that provides even parity over the previous STS-1 frame. The BIP-8 is determined by source **202** after the previous STS-1 frame is scrambled at source **202** prior to an electrical-to-optical conversion to the OC-1 signal. Upon receipt of the BIP-8, multiplexer **210** can determine whether a received scrambled STS-1 contains any errors.

After the error calculation and subsequent unscrambling, the STS-1 is provided as one of the low-speed inputs to multiplexer **210**. If multiplexer **210** is an OC-48 system, 48 STS-1s are byte-interleaved multiplexed into a STS-48 signal. After scrambling, the STS-48 signal is converted into an OC-48 signal for transmission to regenerator **252**. In this process, note that errors can be generated internally by multiplexer **210**. For example, a multiplexing card (not shown) within multiplexer **210** could introduce errors into the SPE of one of the 48 STS-1 signals. Since these errors were introduced prior to the scrambling of the STS-48 signal, the errors would not be detected by the line and section entity error calculations. These errors will be detected by the path entity error detection process. Specifically, the PMP associated with destination **204** can monitor the errors and generate a path PAS.

As noted above, multiplexer **210** can multiplex 48 STS-1 s into the OC-48 signal. Each of these 48 STS-1 s could traverse independent paths throughout the network and terminate on independent destinations. If multiplexer **210** generates errors on each of the 48 STS-1s, then potentially 48 separate STS-1 path PASs could be generated. Correlation between these path PASs could quickly identify multiplexer **210** as the root cause of all the error activity.

FIG. **6** illustrates the path PAS correlation process. This process begins at step **602** where a layer in network management system **100** receives a plurality of path PASs. Next, at step **604**, the layer determines whether it has entire information for all of the paths that have reported a PAS. If the layer determines at step **606** that it does not have enough information, the root cause analysis must be performed by one of the higher layers in network management system **100**. This is illustrated by step **606**. If the layer determines at step **606** that it does have enough information, then the process continues to step **608**. At step **608**, the layer determines whether a common line entity exists. If the layer determines

at step **608** that a common line entity does not exist then the process ends. Conversely, if the layer determines at step **608** that a common line entity does exist, a possible root cause of the problem is identified at step **610**.

As described above, this possible root cause may represent a convergence point of paths that generate path PASs. By identifying a convergence point, the layer bypasses redundant processing of the individual path PASs. Speed and efficiency of error detection and correction is thereby improved.

In a second embodiment of the present invention, layers within network management system **100** use raw performance monitoring (PM) data to identify root causes of problems in the network. One goal of raw PM data analysis is to identify network problems at the earliest possible stage. In other words, it is desirable for a service provider to identify a potential network problem before any significant effects are felt by the customer. In this manner, the service provider is able to correct a problem before the customer is aware that a problem exists.

One example of a potential problem is the existence of "dribble" errors. In this context, dribble errors are used to refer to a situation where a system is operating satisfactorily but not error-free. Errors that are reported by the monitoring points to the layers in network management system **100** are typically not large enough to cause a monitoring point to declare a PAS. Ordinarily, these non-zero error reports would not prompt any action by a service provider. However, these non-zero errors could indicate that a network element is operating at a point near the acceptable tolerance levels. Numerous examples exist. Intermittent errors could simply be caused by a dirty connector in a fiber-optic link. In other cases, synchronization shifts could cause jitter tolerance levels to be exceeded. In other examples, temperature or humidity variations could cause network element performance to periodically degrade.

Regardless of the cause, intermittent non-zero error reports will be provided to the layers in network management system **100**. Each layer in network management system **100** can independently analyze the existence of non-zero error activity over a period of time. Experience in the analysis of the non-zero error activity can lead to a correlation between specific patterns of error activity with the existence of specific network problems. Any means of statistical analysis can be used as a means for triggering a root cause analysis process. For example, if specific patterns of error activity are known to lead to certain failures, general pattern recognition systems (e.g., neural networks) can be used for triggering purposes. As noted above, this statistical analysis can be performed at each layer of network management system **100** simultaneously. The only difference in processing is the scope of PM data that is available to an element in the particular layer in network management system **100**.

FIG. **7** illustrates a flow chart of the path and line entity correlation process in the second embodiment. The process begins at step **702** upon the generation of a raw PM path PAS. A raw PM path PAS is generated by one of the layers in network management system **100** upon an analysis of the reported raw PM path data. As noted above, analysis of patterns of error activity over time could cause a layer in network management system **100** to identify a potential network problem. Note that a raw PM path PAS is generated by a layer in network management system **100** while a regular path PAS is generated by a monitoring point associated with a network element. As further illustrated at step **702** of FIG. **7**, a regular path PAS could also be used in the unreported root cause analysis.

After a raw PM path PAS is generated or a regular path PAS is received by a layer in network management system, the layer determines whether it has enough information to determine the root cause. This process is represented by the loop of steps **704** and **706**. After a layer in network management system determines at step **706** that it has enough information to determine the root cause, the process continues to step **708**.

If a layer determines, at step **708**, that the path entity does not include distinct line entities, then the path-line correlation process of FIG. **7** ends. In this case, the unreported root cause analysis cannot be further narrowed to a part of the path entity. However, if the layer determines, at step **708**, that the path entity does include distinct line entities, then the layer next determines, at step **710**, whether a line entity within the path entity has reported non-zero error activity.

If none of the line entities within the path entity has reported non-zero error activity, then the path-line correlation process ends. As noted above, this situation may result if the monitoring points associated with the line entities have not have been activated. Subsequent activation of the monitoring points will allow further unreported root cause analysis in a later monitoring period.

Finally, if the layer determines, at step **710**, that a line entity has reported non-zero error activity, then the root cause of the network problem is narrowed to a particular line entity. Additional root cause analysis then proceeds at step **712** to further identify the root cause of the problem within the identified line entity.

FIG. **8** illustrates a second method of unreported root cause analysis that is based upon the correlation of error activity in line entities and section entities. The line-section correlation process begins at step **802** where a layer in network management system **100** generates a raw PM line PAS or receives a regular PAS from a monitoring point. After a raw PM line PAS is generated or a regular path PAS is received by a layer in network management system, the layer determines whether it has enough information to determine the root cause. This process is represented by the loop of steps **804** and **806**. After a layer in network management system determines at step **806** that it has enough information to determine the root cause, the process continues to step **808**.

At step **808**, the layer determines whether a distinct section entity exists for the line entity. If element manager **143** determines, at step **808**, that the line entity does not include distinct section entities, then the line-section correlation process of FIG. **8** ends. In this case, the unreported root cause analysis cannot be further narrowed to a part of the line entity. However, if the layer determines, at step **808**, that the line entity does include distinct section entities, then the layer next determines, at step **810**, whether a section entity within the line entity has reported non-zero error activity.

If none of the section entities within the line entity has reported non-zero error activity, then the line-section correlation process ends. Finally, if the layer determines, at step **810**, that a section entity has reported non-zero error activity, then the root cause of the network problem is narrowed to the particular section entity. Since the section entity is the lowest level of granularity, the unreported root cause analysis is complete. Thus, at step **812**, the section entity is identified as the root cause of the network problem.

As described above, a function of the unreported root cause analysis is to correlate non-zero error activity. Raw

PM path PASs can be correlated with non-zero zero error activity on a line entity and raw PM line PASs can be further correlated to non-zero error activity on a section entity. In a similar manner to the reported root cause analysis, the unreported root cause analysis correlates non-zero error activity between various signal levels in the transport hierarchy. In this correlation process, the highest rate in the transport signal hierarchy experiencing simultaneous error activity is identified. FIGS. **9A–9D** illustrate this correlation process. In the following description, assume that a layer in network management system **100** has either generated a raw PM DS1 path PAS or received a regular DS1 PAS from a monitoring point.

The transport level determination process begins at step **902** of FIG. **9A**. At step **902**, the layer determines whether the DS1 channel is mapped into a DS3 channel or into a VT-1.5 channel. If the DS1 channel is mapped into a DS3 channel, the process continues at step **906**. At step **906**, the layer determines whether the DS3 in which the DS1 is mapped has reported non-zero error activity. In a similar manner to step **906**, step **908** is invoked if the layer determines, at step **902**, that the DS1 is mapped into a VT-1.5 channel. At step **908**, the layer determines whether the VT-1.5 in which the DS1 is mapped has reported non-zero error activity. In the simplest example for either scenario, the layer determines whether non-zero error activity has been recorded for the same monitored parameter identified in the original statistical analysis.

If the determination at either step **904** or step **906** determines that the VT-1.5 or DS3, respectively, has not reported non-zero error activity, then the layer, at step **908**, reports the DS1 raw PM PAS to the next highest layer in network management system **100**. Next, at step **910**, the highest transport level is identified as a DS1 and the process ends.

Returning to step **906**, if the DS3 in which the DS1 is mapped does report non-zero error activity, the process continues to step **912** of FIG. **9B**. At step **912**, the layer determines whether the DS3 is mapped into a STS-1. If the DS3 is not mapped into an STS-1, the DS3 raw PM PAS is reported to the next highest layer at step **916**. Thereafter, the highest transport level is identified as a DS3 at step **918**. If the layer determines, at step **914**, that the DS3 is mapped into an STS-1, the layer then determines whether the STS-1 has reported non-zero error activity at step **914**. If non-zero error activity was not reported, the DS3 raw PM PAS is reported to the next highest layer.

Returning to step **904**, if the VT-1.5 in which the DS1 is mapped does report non-zero error activity, the process continues to step **920** of FIG. **9C**. At step **920**, the layer determines whether the STS-1 in which the VT-1.5 is mapped has reported non-zero error activity. If the associated STS-1 in which the VT-1.5 is mapped has not reported non-zero error activity, the VT-1.5 raw PM PAS is reported to the next highest layer at step **922**. Next, the highest transport level is identified as a VT-1.5 channel at step **924**.

If the layer determines at either step **914** or step **920** that a STS-1 has reported non-zero error activity, the process continues at step **926** of FIG. **9D**. At step **926**, the layer determines whether the STS-1 is mapped into an OC-48 system or an OC-3/12 system. If the layer determines at step **926** that the STS-1 is mapped into an OC-3/12 system, the layer then determines, at step **928**, whether the OC-3/12 system has reported non-zero error activity. If the OC-3/12 system has reported non-zero error activity, the highest transport level is identified as a OC-3/12 at step **932**. Conversely, if the OC-3/12 system has not reported non-zero error activity, a STS-1 raw PM PAS is reported to the next highest layer at step **934**. The highest transport level is then identified as a STS-1 at step **936**.

If the layer determines at step **926** that the STS-1 is mapped into an OC-48 system, the layer then determines, at step **930**, whether the OC-48 system has reported non-zero error activity. If the OC-48 system has reported non-zero error activity, the highest transport level is identified as a OC-48 at step **938**. Conversely, if the OC-48 system has not reported non-zero error activity, a STS-1 raw PM PAS is reported to the next highest layer at step **934**. In this case, the highest transport level is identified as a STS-1 at step **936**.

As the flow chart of FIGS. **9A–9D** illustrate, the present invention seeks to identify the highest transport level that is experiencing simultaneous error activity. Note again that the identification process of FIGS. **9A–19D** need not begin at the DS1 level. For example, the statistical analysis could identify a potential problem at the DS3 level. In this case, the process described in FIGS. **9A–9D** begins at step **912**.

FIG. **10** illustrates the process of correlating path PASs. This process begins at step **1002** where a layer in network management system **100** identifies a plurality of path PASs. These path PASs include both raw PM path PASs and regular PASs. The raw PM path PASs may be generated by any of the layers within network management system **100**.

After the plurality of path PASs are identified, the layer determines at step **1004** whether it has entire information for all of the paths that have reported a PAS. If the layer determines at step **1004** that it does not have enough information, the root cause analysis must be performed by one of the higher layers in network management system **100**. This is illustrated by step **1008**. If the layer determines at step **1006** that it does have enough information, then the process continues to step **1008**. At step **1008**, the layer determines whether a common line entity exists. If the layer determines at step **1008** that a common line entity does not exist then the process ends. Conversely, if the layer determines at step **1008** that a common line entity does exist, a possible root cause of the problem is identified at step **1010**. In a similar manner to the reported root cause analysis, the correlation of path PASs allows a layer to bypass redundant processing of the path PASs individually.

In one embodiment, the invention is directed to a computer system operating as discussed herein. For example, functions in each layer of network management system **100** is implemented using computer systems. An exemplary computer system **1102** is shown in FIG. **11**. The computer system **1102** includes one or more processors, such as processor **1104**. The processor **1104** is connected to a communication bus **1106**.

The computer system **1102** also includes a main memory **1108**, preferably random access memory (RAM), and a secondary memory **1110**. The secondary memory **1110** includes, for example, a hard disk drive **1112** and/or a removable storage drive **1114**, representing a floppy disk drive, a magnetic tape drive, a compact disk drive, etc. The removable storage drive **1114** reads from and/or writes to a removable storage unit **1116** in a well known manner.

Removable storage unit **1116**, also called a program storage device or a computer program product, represents a floppy disk, magnetic tape, compact disk, etc. As will be appreciated, the removable storage unit **1116** includes a computer usable storage medium having stored therein computer software and/or data.

Computer programs (also called computer control logic) are stored in main memory and/or the secondary memory

1110. Such computer programs, when executed, enable the computer system 1102 to perform the features of the present invention as discussed herein. In particular, the computer programs, when executed, enable the processor 1104 to perform the features of the present invention. Accordingly, such computer programs represent controllers of the computer system 1102.

In another embodiment, the invention is directed to a computer program product comprising a computer readable medium having control logic (computer software) stored therein. The control logic, when executed by the processor 1104, causes the processor 1104 to perform the functions of the invention as described herein.

In another embodiment, the invention is implemented primarily in hardware using, for example, a hardware state machine. Implementation of the hardware state machine so as to perform the functions described herein will be apparent to persons skilled in the relevant art(s).

While the invention has been particularly shown and described with reference to preferred embodiments thereof, it will be understood by those skilled in the relevant art that various changes in form and details may be made therein without departing from the spirit and scope of the invention.

What is claimed is:

1. A method, in a layer of a network, management system, for identifying a root cause of a problem in a provisioned channel in a network, the provisioned channel being routed through a plurality of network elements, the method comprising the steps of:

(1) receiving performance monitoring data gathered for section, line and path entities by a plurality of monitoring points during, a monitoring period, each of said plurality of monitoring points being associated with a network element; and

(2) identifying a correlation between any error activity in said section, line and path entities as indicated by said performance monitoring data that is received from at least two different ones of said plurality of monitoring points to locate a root cause of a problem in either said section, line or path entities of the provisioned channel.

2. The method of claim 1, wherein said step (2) comprises the steps of:

(a) analyzing performance monitoring data at a first signal transport level reported from a first monitoring point to determine whether a potential problem exists;

(b) identifying a second signal transport level that experiences corresponding error activity, said error activity being reported by a second monitoring point, wherein said first signal transport level is mapped into said second signal transport level; and

(c) identifying a third monitoring point upstream of said second monitoring point that reports corresponding error activity.

3. The method of claim 2, wherein said step (b) is repeated until a highest transport level is identified.

4. The method of claim 2, further comprising the step of discontinuing further processing for problem alert signals that are received by the layer in the network management system from monitoring points downstream from said first monitoring point, wherein said problem alert signals correspond to the error activity reported by said first monitoring point.

5. The method of claim 1, wherein said step (2) comprises the steps of:

(a) analyzing performance monitoring data reported by a monitoring point associated with a line entity to determine whether a potential problem exists;

(b) determining whether said line entity includes a plurality of section entities;

(c) determining whether a monitoring point associated with a section entity within said line entity has reported corresponding error activity; and

(d) initiating a problem handling process for said section entity, if a monitoring point associated with a section entity has reported corresponding error activity.

6. The method of claim 5, further comprising the step of:

(e) initiating a problem handling process for said line entity, if a monitoring point associated with a section entity has not reported corresponding error activity.

7. The method of claim 5, further comprising a step before said step (b) of determining the topology of the line entity.

8. The method of claim 1, wherein said step (2) comprises the steps of:

(a) analyzing performance monitoring data reported by a monitoring point associated with a path entity to determine whether a potential problem exists;

(b) determining whether said path entity includes a plurality of line entities;

(c) determining whether a monitoring point associated with a line entity within said path entity has reported corresponding error activity; and

(d) initiating a problem handling process for said line entity, if a monitoring point associated with a line entity has reported corresponding error activity.

9. The method of claim 8, further comprising the step of:

(e) initiating a problem handling process for said path entity, if a monitoring point associated with a line entity has not reported corresponding error activity.

10. The method of claim 9, further comprising a step before said step (b) of determining the topology of the path entity.

11. The method of claim 1, wherein said step (2) comprises the steps of:

(a) analyzing performance monitoring data reported by monitoring points associated with a first and a second path entity to determine whether a potential problem exists;

(b) determining whether said first and second path entities include a common line entity; and

(c) initiating a problem handling process for said common line entity, if a common line entity exists.

12. The method of claim 11, further comprising a step before said step (b) of determining the topology of said first and second path entities.

13. A system for identifying a root cause of a problem in a provisioned channel in a network, the provisioned channel being routed through a plurality of network elements, comprising:

(1) means for receiving performance monitoring data gathered for section, line and path entities from a plurality of monitoring points during a monitoring period, each of said plurality of monitoring points being associated with a network element; and

(2) means for identifying a correlation between any error activity in said section, line and path entities as indicated by said performance monitoring data that is received from at least two different ones of said plurality of monitoring points to identify a root cause of a problem in either said section, line or path entities of the provisioned channel.

14. The system of claim 13, wherein said means for identifying comprises:

means for analyzing performance monitoring data at a first signal transport level reported from a first monitoring point to determine whether a potential problem exists;

means for identifying a second signal transport level that experiences corresponding error activity, said error activity being reported by a second monitoring point, wherein said first signal transport level is mapped into said second signal transport level; and

means for identifying a third monitoring point upstream of said second monitoring point that reports corresponding error activity.

15. The system of claim **14**, further comprising means for identifying a highest signal transport level that experiences corresponding error activity.

16. The system of claim **14**, further comprising means for discontinuing further processing for problem alert signals that are received by the layer in the network management system from monitoring points downstream from said first monitoring point, wherein said problem alert signals correspond to the error activity reported by said first monitoring point.

17. The system of claim **13**, wherein said means for identifying comprises:

means for analyzing performance monitoring data reported by a monitoring point associated with a line entity to determine whether a potential problem exists;

means for determining whether said line entity includes a plurality of section entities;

means for determining whether a monitoring point associated with a section entity within said line entity has reported corresponding error activity; and

means for initiating a problem handling process for said section entity, if a monitoring point associated with a section entity has reported corresponding error activity.

18. The system of claim **17**, further comprising:

means for initiating a problem handling process for said line entity, if a monitoring point associated with a section entity has not reported corresponding error activity.

19. The system of claim **17**, further comprising means for determining the topology of the line entity.

20. The system of claim **13**, wherein said means for identifying comprises:

means for analyzing performance monitoring data reported by a monitoring point associated with a path entity to determine whether a potential problem exists;

means for determining whet her said path entity includes a plurality of line entities;

means for determining whether a monitoring point associated with a line entity within said path entity has reported corresponding error activity; and

means for initiating a problem handling process for said line entity, if a monitoring point associated with a line entity has reported corresponding error activity.

21. The system of claim **20**, further comprising:

means for initiating a problem handling process for said path entity, if a monitoring point associated with a line entity has not reported corresponding error activity.

22. The system of claim **21**, further comprising means for determining the topology of the path entity.

23. The system of claim **13**, wherein said means for identifying comprises:

means for analyzing performance monitoring data reported by monitoring points associated with a first and a second path entity to determine whether a potential problem exists;

means for determining whether said first and second path entities include a common line entity; and

means for initiating a problem handling process for said common line entity, if a common line entity exists.

24. The system of claim **23**, further comprising means for determining the topology of said first and second path entities.

25. A computer program product, comprising:

a computer usable system medium having computer readable program code means embodied in said medium that identifies a root cause of a problem in a provisioned channel in a network, the provisioned channel being routed through a plurality of network elements, said computer readable program code means comprising:

first computer readable program code means for causing a computer to effect a reception of performance monitoring data gathered for section, line and path entities from a plurality of monitoring points during a monitoring period, each of said plurality of monitoring points being associated with a network element; and

second computer readable program code means for causing a computer to effect an identification of a correlation between any error activity in said section, line and path entities as indicated by said performance monitoring data that is received from at least two different ones of said plurality of monitoring points to identify a root cause of a problem in either said section, line or path entities of the provisioned channel.

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